Neurology

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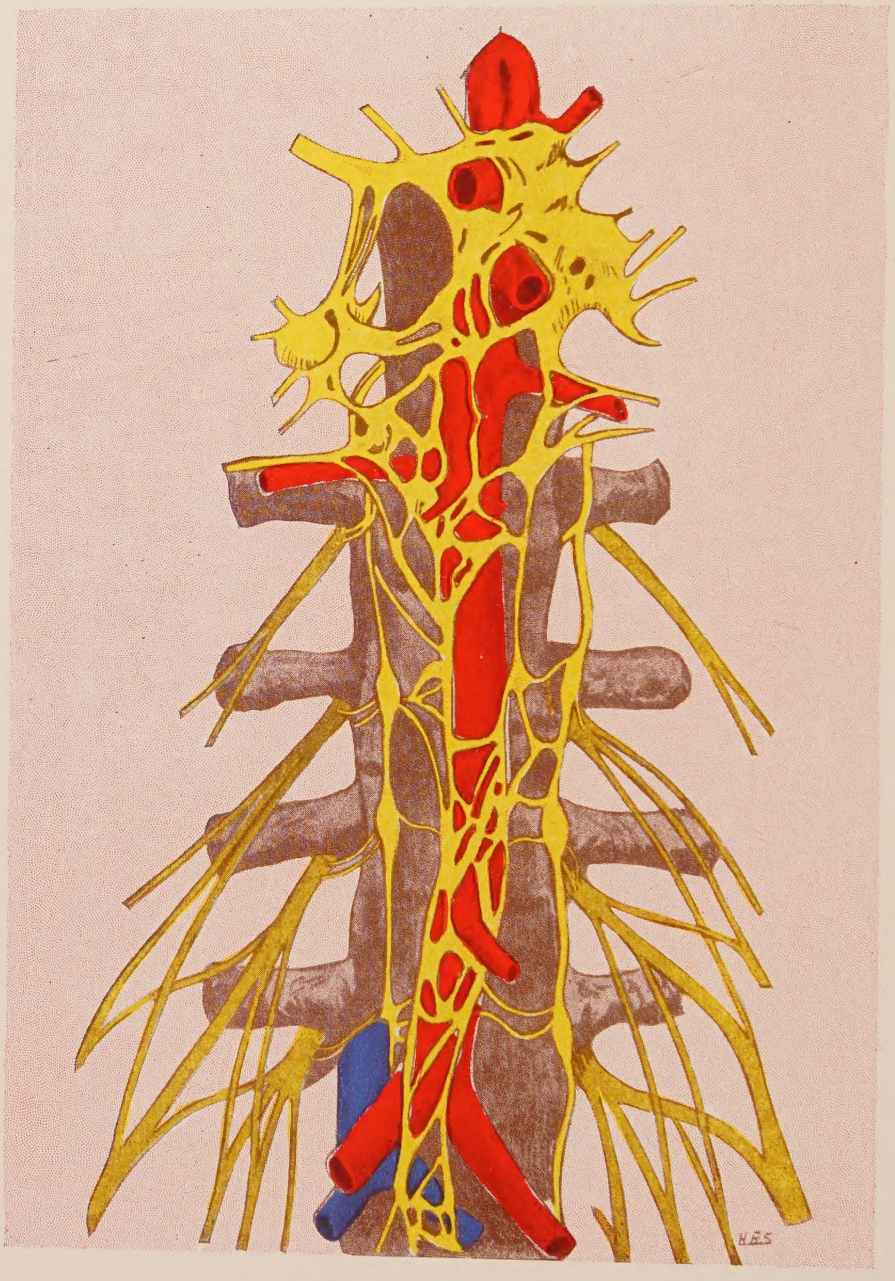
TEXTBOOK OF NEUROLOGY



Coeliac Plexus and Abdominal Sympathetic

A Textbook of

NEUROLOGY

Arranged for the Classroom and for Ready Reference
by the Practitioner.

By

JOY M. LOBAN

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"Author of "Technic and Practice of Chiropractic" and co-author of "Diet and Exercise."

With 117 Illustrations

By

H. R. SPRINGER

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This Book is Dedicated to Dr. Chas. R. Bunn, whose invaluable counsel, unfailing friendship, and sustained confidence have made it possible.

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A PRELIMINARY SURVEY

Those who approach the study of the Nerve System of Man with the desire to acquire an approximately complete knowledge of it will do well first of all to appreciate the gravity and magnitude of the task. Not only is the Nerve System the most important set of tissues in the human organism but the most complex and difficult of comprehension. So near does it lie to Life itself that to discover the ultimate meaning and explanation of every phenomenon connected with nerve action would be to arrive at, or nearly approach, an understanding of the Infinite Plan in accordance with which the entire universe exists and operates—or is operated.

Science has made tremendous strides in the past three centuries toward elucidation of the mysteries of nerve action, but there remains a vast field for further exploration, a great borderland of question and conjecture.

The fact that not everything is known about this interesting subject does not, however, unduly circumscribe our practical application of the tremendous fund of accurate knowledge which we do possess, thanks to the untiring patience of thousands of investigators in the fields of anatomy, physiology, embryology, histology, and pathology. We already have a great deal of useful information —useful especially to those whose calling it is to heal the sick by one means or another. This is available in a multitude of books, old books and new, books in many languages. It would seem that everything of value which could be written about the Nerve System up to this time has been written.

On the contrary there are a few—not many—important facts which have not been clearly set down in print; these are chiefly the results of comparatively recent clinical experiences acquired during the use of methods of combating disease directed solely to the discovery of nerve influence in the production of diseased states and the modification of such influence by treatment. These few new facts and principles can only be thoroughly comprehended in relation to all the other knowledge available on the subject. It seems necessary therefore to gather in a single volume a comprehensive summary of Neurology and to condense it sufficiently to bring it within reach of the average student. To do this it becomes necessary to draw freely from humanity's accumulated data on the subject, to consult and perhaps paraphrase many authors,

to repeat much of what has already been written and studied by thousands, at times almost in the identical words of the original authors or their followers. This borrowing of the fruits of the labor of preceding generations is as unavoidable in the compilation of a textbook on Neurology as in the writing of an arithmetic or of a textbook on English. A volume containing nothing previously known, and made up only of the author's strictly original observations, would be unreadable and quite useless; we are obliged to use past knowledge as the bridge upon which the mind may cross to new knowledge.

There is another reason for arranging the essential facts and theories relating to the Nerve System in a single book. This is the difficulty experienced by some students in locating among the volumes of an enormous bibliography the particular parts or sections which will serve their needs. Usually the Nerve System has been considered merely as a part of the general study of the human body. In anatomy, it is one section among many; likewise in physiology. Its embryology is likely to be lost in a discussion of general embryology because writers on that subject fail to perceive the paramount importance of nerve tissue and the immense significance of some of the events of its pre-natal development.

There are, of course, a few books devoted wholly to the subject but these are commonly monographs which occupy a very strictly circumscribed field and fail to show the subject in its entirety, and therefore to develop in the student a proper sense of proportion. Some of these books, in their limited fields, are masterpieces of detail, so that by their very minuteness and profundity they are rendered valueless to the average seeker after knowledge. A whole lifetime would be too short a time in which to acquire, in unlimited detail, everything which can be known about nerves.

What is most urgently needed seems to be a book which, in a comprehensive way but without too much minutia, covers the field of Neurology and leads up to practical conclusions. The author endeavors to meet this need, with frank and grateful acknowledgment to the entire world of science for the major part of the information here compiled and rewritten, and with the belief that he has added to this great foundation a small but valuable superstructure of new facts and a few hypotheses capable of being applied to the real benefit of humanity.

The subjects which may properly be included under the general term "Neurology" are those which deal with the structure of the

Nerve System; explain its actions in relation to the other organs of the body and to the general environment; trace its mutations from earliest embryonic appearance to adulthood, make clear the gradual elaboration and organization of this system through an extremely extended phylogenetic past; describe those pathologic processes which most commonly affect nerve tissue; discuss in detail the diagnosis of nerve lesions; and finally, set forth as a result of these considerations a statement of those philosophic concepts which are most closely linked with nerve action. These subdivisions aid each in understanding of the others and together comprise most of what is valuable to the student of nerves. It is advised that they be studied in the order in which they are presented, because this is believed to be the most logical and easiest method of approach.

NEUROLOGY

ANATOMY OF THE NERVE SYSTEM

The Nerve System of Man is a highly complex structure, made up of a multitude of individual elements called neurons, aggregated together for the formation of the nerve organs, and supported by a quantity of special cementing substance, the neuroglia, and by connective tissue. This aggregation of neurons into organs and of organs into a system serves, as a whole, the purposes of establishing and maintaining a relationship between the various parts of the human body, and between the body and its environment. It is the means by which man becomes aware of the existence of an external world and reacts toward it; it is the mechanism by which is brought about harmonious co-operation among all the other organs of which the human body is composed; it is the seat of consciousness and of all the phenomena appertaining to mind; it exercises a governing or controlling influence over all the body's multifarious activities.

The organs of the nerve system are divided for convenience in study into two groups, the **Central Organs,** consisting of the Brain and Spinal Cord, and the **Peripheral Organs,** which are the Cranial Nerves, attached to the brain, the Spinal Nerves, attached to the spinal cord, and the Sympathetic, Autonomic, or Vegetative Nerve System, composed of a double chain of ganglia adjacent to the vertebral column, three great pre-vertebral plexuses situated in the thoracic, abdominal, and pelvic cavities respectively, and numerous lesser ganglia and plexuses, together with the connecting nerve-cords which bind these together and to the cerebrospinal system.

The Brain and Spinal Cord together with their directly attached Cranial and Spinal Nerves are known collectively as the **Cerebrospinal System.**

HISTOLOGY OF NERVE TISSUE

The earlier view of the minute structure of the nerve system held that it was made up of two distinct elements, nerve cells *(neurocytes)* and nerve fibres, and that these were supported within the central nerve system by a ground substance, also of neural origin, the neuroglia. More recent investigations have disclosed the fact that the nerve fibres are prolongations or processes of the neurocytes; Waldeyer and others have developed the opinion that the nerve cell with its processes is the structural and functional unit of the nerve system; to this unit the name **neuron** has been given.

The Neuron Theory.

According to this theory all the organs of the nerve system are made up of aggregations of individual neurons. These vary greatly in size and shape but all have certain properties in common. Most neurons have a cell body, dendrites *(dendrons)* and an axon *(axis cylinder)*. The dendrites are usually short, branching processes which terminate in the vicinity of the cell body; the axon is usually a much elongated process extending for a considerable distance. Dendrites are cellulipetal in function, i. e., they carry stimuli toward the cell body; axons are cellulifugal in function, carrying stimuli away from the cell body; this is the only real distinction between the two kinds of processes for there are short as well as long axons while one set of dendrites, the peripherally directed processes of the bipolar cells of the dorsal root ganglia, are quite as long as the longest axons, though cellulipetal in their conduction of stimuli.

Fig. 1
Schema of Typical Neuron
A, Dendrite; B, Cell Body; C, Axon; D. Neurilemma; E, Collateral; F, Myelin Sheath; G, End-Tuft

Neurons do not communicate with each other except by contact. There is no anastamosis of nerve elements such as is found in the blood-vascular system. In embryonic life each neuron is distinct and separate from the others. All the neurons are present at birth, although some of them do not begin to function until after birth. Evidence of the separateness of neurons is found in the above fact and also in the fact that when degenerative processes develop in the nerve system they never pass from one set of neurons to another. Some investigators have cast doubt upon this doc-

trine of individuality of neurons but the weight of evidence seems to favor it.

A neuron may be defined as a nerve cell, with its processes, constituting the morphologic, histologic, and physiologic unit of the nerve system.

Neurocytes.

Nerve cells differ from nerve fibres in color; the former are somewhat grayish in hue while the latter, with their investing sheaths, are usually white. The preponderance of cells over fibres on the surface of the brain, in the basal ganglia, throughout the central fluted column within the spinal cord, and in the ganglia, causes these parts of the nerve system to be called **gray matter.** The remaining parts of the central system are called **white matter** because they are occupied chiefly by nerve fibres. Strictly speaking, the gray matter has a pinkish gray hue and the white shows a faintly yellowish tinge.

Originally all neurocytes are oval, but during the course of development they acquire various shapes such as pear-shaped, fusiform, pyramidal, stellate, etc. They also vary considerably in size from the large pyramidal cells of the cerebral cortex, which are almost visible to the unaided eye, to some cells in the olfactory bulb about 1/3,000th of an inch in diameter. From the total bulk of gray matter in relation to the size of the individual cells it will be seen that the total number of neurocytes is enormous and uncountable.

Each cell is a mass of protoplasm, containing a nucleus and a distinct nucleolus. The substance of the cell is said to be of two different kinds, a reticular network of neurofibrils which are continued into the extended processes of the cell, and a more fluid hyaloplasm, or karyolymph, permeating the interstices of the reticulum. The existence of a special neuro-reticulum has been doubted by some investigators who hold that the appearance of fibrils in the neurocyte and their apparent persistence in the axon are artifacts due to staining methods. There is no cell membrane.

Dendrites.

The dendrites are direct projections of the protoplasm of the cell; they extend in various directions but are usually attached at one side, or pole. Each dendrite begins to branch shortly after its

emergence from the cell and continues to divide until its tendrils form an intricate interlacement; these tendrils, however, do not unite with each other or with the processes of any other neuron but communicate by contact only. In some instances the dendrites form a thick basketwork about the cell body, especially in the cortex of the cerebrum and cerebellum. All dendrites are afferent to the cell body in their function; that is, they gather stimuli and transmit them to the interior of the cell where the stimuli serve to arouse the cell to its characteristic action and thus to evoke responsive impulses. Exception to this description of the general appearance of dendrites must be noted in the case of the long afferent fibres of the spinal and some cranial nerves; these are dendrites in function, since they gather impressions at their periphery for transmission to their cells of origin in the dorsal root and cranial nerve ganglia, yet they have the appearance and makeup of axons. q. v.

Axons.

The first process given off by the developing nerve cell is the axon. It grows from a cone-shaped projection upon the surface. It is usually elongated to a considerable distance and throughout its course maintains a uniform diameter and a clear or hyaline appearance. A short distance from the cell body it acquires sheaths and the axon together with these investments is commonly called a **nerve fibre.** Like the cell of which it is a prolongation, the axon is made up of semifluid protoplasm; whether or not it contains minute parallel fibrillæ is a moot question.

Nerve cells are classified as **monaxonic, diaxonic,** or **polyaxonic** according as they give off one, two, or more axons. In man most axons are monaxonic. Nerve cells are classified as **unipolar, bipolar,** and **multipolar** according to whether all processes are attached on one side or on two sides, or on several. Bipolar cells are most common; these include the cells of the spinal nerve ganglia and of the ganglia of the afferent cranial nerves, which appear unipolar inasmuch as they seem to give forth a single process which divides into two a short distance from the cell. In fact, these cells are definitely bipolar in the embryo but in the process of growth the two processes gradually approach each other and appear to fuse although they do not actually do so.

NEUROGLIA.

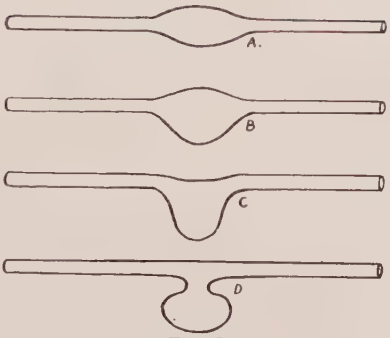

Fig. 2
Stages in Development of Bipolar Cells of Spinal Ganglia

The peculiar cementing or ground substance which surrounds and supports the true nerve tissue within the brain and spinal cord is called neuroglia. It is ectodermal in origin, like nerve tissue, but serves the purpose of a connective tissue and has no nervous function. It consists of cells and fibres of various forms and so arranged as to form a network for the support of the neurons. The fibres may be elongated as in the case of those which run from the vicinity of the central canal of the spinal cord to its periphery to connect with the pia mater, or may be short and repeatedly branched as in the substantis gelatinosa Rolandi which caps the dorsal horn of the cord, or may be laid out in a flattened layer such as is found on the surface of the brain or in the ependymal layer lining the central canal of the cord.

Structure of a Nerve.

The term **nerve** is applied to an aggregation of axons or long dendrites or both together with their investing sheaths. The single axon or dendrite with its neurilemma is commonly called a nerve fibre. A nerve, therefore, is a bundle of nerve fibres with supporting connective tissue coverings. Each individual fibre has a **neurilemma,** except in rare instances within the brain. External to the neurilemma is the **medullary sheath,** if any. A number of such fibres are bound together by a delicate connective tissue called **endoneurium** into a slender bundle called a **funiculus.** A small nerve may consist of a single funiculus but in most nerves there are a number of funiculi bound together into a larger bundle, the **fasciculus.** Several fasciculi may be bound together into a **nerve trunk.** The investing sheath of the funiculus is a lamellated tubular structure, the perineurium, made up of white and yellow elastic fibres, the latter abundant to permit of flexibility. The whole nerve is covered by a membranous sheath of connective tissue, the **epineurium.** The blood-vessels which nourish the nerve trunk are supported by the connective tissue. The fibres of the latter run generally in a longitudinal direction but thin septa are sent inward from the perineurium to connect with the endoneurium.

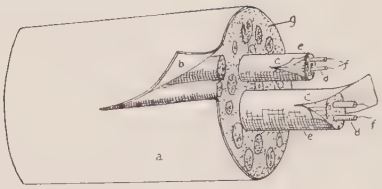

Fig. 3.
Structure of the Nerve Trunk (Schematic)
A, Nerve Trunk; B, Epineurium; C, Perineurium, Surrounding a Fasciculus; D, Endoneurium; E, Fasciculus; Ff, Individual Nerve Fibres; G, Neuroglia

The Neurilemma.

This is a thin, delicate, homogeneous membrane closely investing the protoplasm of the nerve fibre and its myelin and, since it is quite tough and resistent, though elastic, is doubtless intended as a protection for its contents. It is a constituent of almost all nerve fibres although absent from some in the brain.

Medullary Sheath.

The medullary sheath, myelin sheath, or white substance of Schwann, lies between the neurilemma and the axon. It is a clear, semi-fluid, fatty substance which serves to give the whitish color to the nerve fibre. Most of the cerebrospinal neurons are medullated, including those within the brain and cord, whereas the fibres arising in the sympathetic are non-medullated (*amyelinic*). It would appear that the earlier and more primitive nerves were originally, and have since remained, unmedullated, while the intercalated neurons later developed require it for some reason.

Nodes of Ranvier.

At intervals of about seventy-five times the diameter of the nerve fibre, constrictions appear, in which the myelin sheath is interrupted and the neurilemma lies directly contiguous to the axon; it is believed that through these **nodes of Ranvier** nutrition is enabled to enter.

Collaterals.

Some axons give off laterally directed branches having all the properties of the axon itself; these **collaterals** are found chiefly in the brain and spinal cord. They never appear except at the site of one of the nodes of Ranvier.

Within the nerve trunk and passing more or less lateralward through the connective tissue framework from one nerve fibre to terminate upon other fibres, are a number of exceedingly minute nerve fibres called **nervi nervorum.** These are supposed to be

afferent, or sensory in function and to be involved in certain nerve pains, particularly neuralgic pains. There are also minute efferent *(vasomotor)* nerves accompanying and controlling the blood vessels which ramify the nerve sheaths.

Origin of Nerves.

The term "origin" as applied to nerves has been variously, and sometimes loosely, used. If applied to an axon or a dendrite as part of a neuron, it would of course mean the location of the cell body of that neuron. As applied to a nerve trunk it may mean the **real origin,** which is the location of the group of nerve cells from which the fibres of the nerve trunk arise. Thus the real origins of the efferent components of the cranial and spinal nerves lie within the central gray substance of the brain and medulla spinalis respectively, while the real origin of the afferent components of these nerves lie without the central axis in various ganglia situated upon the trunks of the nerves; the real origin of most sympathetic trunks is in sympathetic ganglia. The **superficial** or **apparent origin** of a nerve is the point at which it appears to enter (*or leave*) the central axis. The deep origin, or nuclear connection of a nerve is the group of cells within the central nerve system to which the individual nerve fibres can be traced by histologic methods. These nuclear connections are either **nuclei of origin,** as in the case of the efferent nerves, or **nuclei of termination** in the case of afferent nerves. For example, the real origin of the optic nerve is in the ganglionic layer of the retina, its apparent origin is the optic chiasma on the under surface of the cerebrum, and its deep origin, or nuclear connection, is with the pulvinar of the optic thalamus, the colliculus superior, and the lateral geniculate body.

Ganglia.

A ganglion is chiefly an aggregation of nerve cells and the term is commonly applied to those aggregations outside the central axis. There are, however, cell masses in the brain and medulla spinalis which have all the essential features of ganglia. These are called **nuclei,** or **nidi.** In addition to the cells, which give to the ganglion its grayish color, are contained nerve fibres which are the axons and dendrites of the ganglionic cells or which are the terminals of nerves communicating with the ganglion, blood-vessels, and a connective tissue stroma which supports the nerve

elements. This connective tissue takes the form of an enveloping membrane externally, and extends through the ganglion in the form of septa and trabeculae.

Preganglionic and Postganglionic Fibres.

The fibres entering and leaving a sympathetic ganglion are divided into two groups. The **pre-ganglionic** fibres are those which pass from the cerebrospinal system to the sympathetic carrying nerve impulses from the one to the other; the **post-ganglionic** fibres are those which originate in cells of the sympathetic and pass to the cerebrospinal system or to the general periphery where they serve to innervate non-striated muscle tissue or secretor epithelium. The pre-ganglionic fibres are medullated and the post-ganglionic non-medullated.

Plexuses.

The nerve fibres which collectively make up a nerve trunk at a given point in its course rarely remain in the same association throughout the length of the nerve. Groups of fibres leave one trunk and enter another. Sometimes trunks interchange branches. Wherever there is a repeated branching of nerves and reunion of branches in different combination the arrangement is called a **plexus.** There is no fusing of axons in a plexus; merely a complicated regrouping. It is apparent that this plexiform arrangement permits a given organ, supplied by a single nerve trunk, to establish a much wider connection with the central system than would be the case were it not for the fact that the nerve of ultimate supply to the organ is thus made up of elements arising in not one, but several, central segments.

Nerve Endings.

The efferent or motor nerves have three characteristic terminations, the one in skeletal muscle, another in non-striated muscle, and the third in glands. As the nerve fibre to a skeletal muscle approaches its destination it loses its sheaths, so that a naked axon enters the sarcolemma; within the muscle substance the axon splits into a number of fibrils each of which penetrates a muscle fibre and finally ends in a special mass of protoplasm, a transition substance between nerve and muscle, known as the **motor end-plate.** In non-striated muscle the axon likewise splits into minute terminals, but here the terminals wind a spiral course

around the muscle fibres, sometimes forming a plexiform network, before they pierce the wall of the muscle fibre and end within the sarcoplasm. In glands the axons, which are amyelinic as in non-striated muscle, pierce the substance of the gland to its acinus, then divide and turn outward into the substance of the gland to end by piercing the gland cells.

The afferent or sensory nerves have a variety of peripheral endings. The special sense nerves have highly specialized end organs which will be described in connection with these nerves. In muscle tissue efferent nerves terminate by entering the muscle and becoming connected with a bulb-like structure, the sensor end-plate. Similar end-plates have been observed in tendons.

THE SPINAL CORD OR MEDULLA SPINALIS

That part of the central nerve system contained within the vertebral, or neural, canal is called the **medulla spinalis.** It is an elongated, almost cylindrical structure, slightly flattened from before backward, which is continuous with the brain above and extends from the level of the upper border of the atlas above to the level of the lower border of the first lumbar vertebra or the upper border of the second. Its average length in the male is about 18 in. and in the female 17 in.; it thus occupies about two-thirds of the length of the column in the adult. In movements of the vertebral column the lower end of the medulla is drawn slightly upward, so that its relation to the vertebrae is variable within limits. As late as the third month of foetal life the medulla occupies the entire length of the canal; thereafter the vertebral column increases in length more rapidly than the medulla and pushes downward so that the medulla appears to recede up the canal. The nerves attached to the lower third of the medulla are elongated during this growth to retain their foramina of exit from the column and so form a series of descending strands below the termination of the medulla, known from its appearance as the **cauda equina;** the cauda equina is made up of the lumbar, sacral, and coccygeal nerves which, after leaving the medulla, descend to their respective foramina of exit. The caudal termination of the medulla is in a conical projection, the **conus medullaris.** From its tip a slender thread extends downward to be attached to the tip of the coccyx; this is the **filum terminale.**

Diameters and Enlargements of the Medulla Spinalis.

The antero-posterior diameter is slightly less than a half-inch; the lateral diameter is slightly greater and varies somewhat at different levels. It reaches its greatest dimension opposite the fifth or sixth cervical vertebra, where it measures 13 to 14 mm. The **cervical enlargement** is a fusiform swelling which begins gradually at the upper end of the spinal medulla, increases in width to a point opposite the fifth or sixth vertebra, then diminishes until it disappears, blending into the regular contour of the remainder of the cord at the level of the second thoracic vertebra. A similar but slightly smaller swelling is the **lumbar enlargement** reaching from the level of the tenth thoracic vertebra to a point opposite the twelfth where it attains a maximum breadth of from 11 to 13 mm.

and then gradually dwindles into the conus medullaris. These enlargements correspond to the segments of the cord in which are located the motor cell groups controlling the complex and varied movements of the fore-limbs and hind-limbs; an increase in the bulk of internal gray matter at these levels accounts for the total enlargements of the cord.

The vertebral canal is at all levels considerably larger than the medulla spinalis, permitting some freedom of movement when the column is flexed or twisted. This free space surrounding the spinal medulla is only partly occupied by the membranes, the remainder being filled with cerebrospinal fluid.

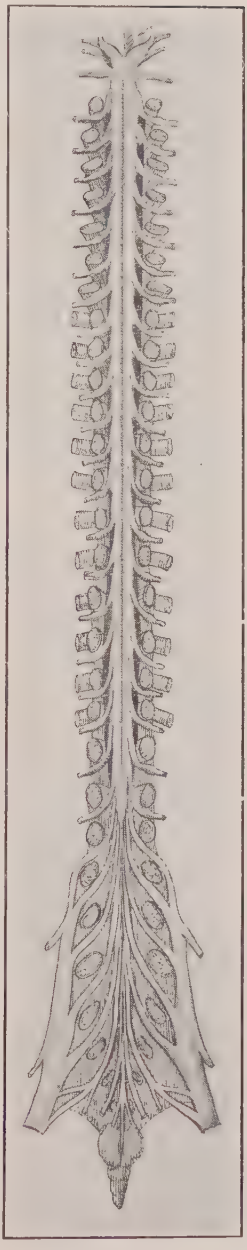

Fig. 4
Drawing of Vertical Section of Spinal Cord
Relation of Nerve Roots to the Cord, Cervical and Lumbar Enlargements, Filum Terminale

Membranes of the Medulla Spinalis.

The spinal medulla is enveloped by three membranes. The inner, the **pia mater,** is a thin, fibrous investment which is attached to the surface of the cord and dips into its ventral longitudinal fissure. It gives off septa which form partial partitions in the interior of the cord. It carries blood-vessels which nourish the outer zone of cord substance. It is continuous through the foramen magnum with the pia mater of the brain. The **arachnoid** is delicate and transparent, presenting meshes through which the cerebrospinal fluid can pass freely. There is a space between the arachnoid and the pia mater called the **subarachnoid space,** which contains cerebrospinal fluid. External to the arachnoid, is a tough, dense, fibrous membrane, the **dura mater;** it gives off tubular sheaths which accompany the emerging spinal nerves as far as their exit from the intervertebral foramina and it extends downward for some distance beyond the end of the cord proper. Like the other two membranes it

is continuous through the foramen magnum with the dura of the brain. Extending from the sides of the spinal cord to the dura are a series of laterally directed slips, the ligamenta denticulata, which serve to suspend the cord within its sheath. Outside the dura the remainder of the canal is filled with soft areolo-fatty tissue.

External Appearance.

When stripped of its outer membranes except the pia mater, which adheres closely, the medulla spinalis is of pinkish hue. Its surface is marked in the midline anteriorly by a deep longitudinal furrow, the **ventral** or **ventromedian fissure,** a true fissure, about 3 mm. deep and lined by pia mater. The floor of the fissure is formed by the anterior white commissure. In the midline posteriorly is the **posterior median sulcus,** a shallow groove from which a neuroglia septum extends forward, dividing the two halves of the cord to a depth of about 4 mm.

Attachment of Nerve-Roots.

The posterior nerve-roots are attached in a linear series along a vertical furrow called the **postero-lateral sulcus.** Between this and the postero-median sulcus, in the cervical region only, is seen a postero-intermediate sulcus which marks the edge of a septum extending forward into the posterior column of the cord and dividing the fasciculus gracilis from the fasciculus cuneatus.

The entire area in front of the line of posterior nerve-roots is the **antero-lateral area.** In the middle of this zone the anterior nerve-roots emerge from the surface in a somewhat irregular series of groups of bundles. The line of the most lateral of these bundles is usually taken as marking a division between the **anterior funiculus** and the **lateral funiculus.** Through the lateral funiculus in the cervical region pass a series of nerve-roots which ascend to join the cranial portion of the spinal accessory nerve within the cranium. Thirty-one pairs of spinal nerves emerge, each by two roots, a ventral, motor, or efferent root, and a dorsal, sensory, or afferent root; the two roots of each nerve unite just within the intervertebral foramen and at or just internal to the point of union the dorsal root shows a tumid swelling which marks the location of the dorsal root ganglion. The direction of the ventral root from its point of emergence is curved outward, downward, and backward; that of the dorsal root is curved outward, downward, and forward. The distance to which the roots extend downward before

uniting increases from above downward so that whereas the roots of the first cervical nerve are almost horizontal, those of the sacral nerves extend almost vertically downward to form part of the cauda equina.

Internal Structure of Medulla Spinalis.

On transverse section the interior of the medulla spinalis is seen to consist of an irregularly shaped core of gray matter surrounded by white matter.

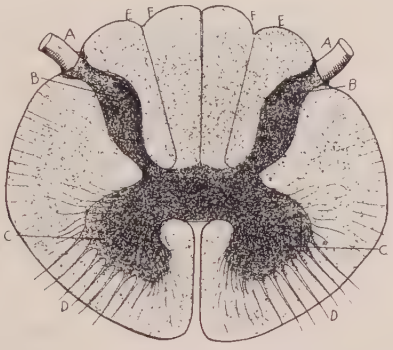

Fig. 5. Drawing of Transverse Section of Spinal Cord. AA, Dorsal Nerve Roots; BB, Cuneate Fasciculi; CC, Gracile Fasciculi; DD, Ventral Gray Horn; EE, Ventral Nerve Roots.

The **gray matter** makes up an irregularly fluted column extending throughout the length of the cord. It is most abundant in the regions of the cervical and lumbar enlargements. The entire cord is made up, as seen in transection, of two symmetric halves and the gray column is also bilaterally symmetric. The two halves are joined across the midline by a transverse gray band, the **gray commissure,** in the middle of which is seen a minute canal, the **central canal.** This canal is lined with ciliated epithelium and filled with cerebrospinal fluid; above it communicates with the fourth ventricle of the brain; it is about 1/30th of an inch in diameter. Each half of the transversely cut gray column discloses the shape of a blunt and somewhat irregular comma, or a crescent, concave laterally. The larger blunt end of the comma is directed forward and outward, the more slender and elongated dorsal end extends backward and outward to the surface of the cord. The former is the **ventral horn,** (*anterior cornu*) and the latter the **dorsal horn** (*posterior cornu*). In the thoracic region appears a less marked **lateral horn** between the other two. The entire area of gray matter in transverse section bears a resemblance to a rough letter H. A coronal plane through the central canal would divide the **anterior column** from the **posterior column.**

The anterior column is broad and somewhat rounded in shape; it does not reach forward as far as the surface of the cord but is separated from it by a layer of white matter which is pierced by the emerging ventral roots. This area is called the **ventral root zone.** The posterior column is thin and slender, directed backward and lateralward, and reaches almost to the surface at the postero-lateral sulcus, where it is capped by a tract of white fibres, the **tract of Lissauer.** As it reaches the tract it is surfaced at its tip by a crescentic, translucent, gelatinous mass of neuroglia, the **substantia gelatinosa of Rolando.** In the curve between ventral and dorsal horns small extended or detached masses of gray matter are found mingled with the white matter in such a way as to form a network known as the **formatio reticularis.**

That part of the transverse gray substance lying in front of the central canal is the **anterior gray commissure** while that behind it is the **posterior gray commissure.** The former is thin and is in contact with the anterior white commissure; it contains a longitudinal vein on either side. The posterior gray column reaches back to the median septum; it is thinnest in the thoracic region and thickest in the conus medullaris. Surrounding the central canal is a layer of neuroglia, **substantia gelatinosa centralis.**

STRUCTURE OF THE GRAY MATTER

The gray matter is composed of nerve-cells with their processes, entering nerve processes from outside cells, neuroglia, and blood-vessels. The neuroglia is in the form of a fibrillar network except for the substantia gelatinosa previously mentioned. The nerve cells are of three varieties; the large multipolar motor cells found in the anterior horn, which give off axons which pass out with the spinal nerves; smaller cells of intrinsic neurons which send axons into the white matter to divide in T-shape, the branches of the T ascending or descending to re-enter the gray matter at a different level and establish association between segments; and cells of Golgi, type II, located in the posterior column and in the substantia gelatinosa of Rolando. The processes of the latter are short and confined to the gray matter.

Nerve-Cells of the Anterior Column.

In the anterior column the nerve-cells are arranged in vertical columns of different lengths. One of these, in the medial part of the anterior column, is the **antero-medial column;** at the segments

C4, C5 it is plainly marked as from C8 to L4 and also at S2, S3, and S4. Posterior to this group but also in the ventral column is the **postero-medial column** as far down as L5. Four additional cell columns are seen in the cervical and lumbar enlargements: these are, **antero-lateral, postro-lateral, post-postero-lateral,** and a **central,** in the last four lumbar and upper two sacral segments.

Lateral Column Nerve-Cells.

These cells are stellate and fusiform and are smaller than the cells of the anterior column; they give origin to axons which join the ventral roots of the spinal nerves and leave them outside the intervertebral foramen to become **preganglionic** fibres directed to the sympathetic ganglia, for which reason their cells of origin are called visceral nerve cells. The lateral column is most marked in the thoracic region, from which region the preganglionic fibres chiefly come. In the medulla oblongata a similar column of cells is called the **lateral nucleus.**

Posterior Column Nerve Cells.

In the dorsal gray substance the nerve cells are gathered in but one distinct column, the **dorsal nucleus,** or **Clark's vesicular** column, and in numerous scattered cell groups. The dorsal nucleus begins at the level of the second or third lumbar segment, reaches maximum size opposite the twelfth thoracic nerve, and thereafter diminishes as it ascends to disappear as a distinct column at the level of the first thoracic or last cervical nerve. Opposite to the third cervical nerve and in the middle sacral region, the **cervical nucleus** and the **sacral nucleus** have similar relations to those of Clark's column. That column receives certain dorsal root fibres after their entrance into the cord and in turn gives off axons which pass lateralward and then ascend in the **dorsolateral spinocerebellar tract.** These root fibres pass obliquely inward and upward after entering the cord and before terminating in the cells of the dorsal nucleus, the lowest cells of which are reached by terminal filaments from afferent lumbar and sacral fibres. The axons of Clark's column in turn slant obliquely upward and outward to the marginal area of the cord before turning upward in the dorsolateral spinocerebellar tract so that this tract first appears in the lower thoracic region.

Golgi cells, type 11, are numerous in the dorsal column; they send axons in various directions through the gray matter, some

ending in the dorsal and some in the lateral and ventral gray of the same and opposite sides. In the substantia gelatinosa of Rolando are many small groups of cells which send axons into the posterior and lateral funiculi of white matter to ascend and come into relation with higher levels of the gray matter.

The entire gray matter is reticulated with nerve fibres; the processes of the cells of the gray matter, both those which remain within it and those which emerge into the white matter and the nerve roots; and the entering processes from cell groups at other levels and from ganglion cells outside the cord.

STRUCTURE OF THE WHITE MATTER

The white matter of the medulla spinalis surrounds the gray substance in such a way as to round out the cylindrical outline of the cord. It is composed largely of nerve fibres enmeshed in a stroma of neuroglia and invested by a neuroglial sheath closely connected to the pia mater. There are both medullated and non-medullated nerve fibres, though the former predominate sufficiently to give a whitish color to the whole mass. The fibres comprise three systems; **projection fibres,** which connect parts of the brain with parts of the spinal medulla; **commissural fibres** which cross the medulla from side to side in the anterior white commissure and serve to bring the gray matter of the two sides into co-operative relationship, and **associative, intrinsic,** or **intersegmental fibres,** which leave the gray matter at one level, travel upward or downward for a distance and then re-enter the gray at a different level to bring two or more segments into physiologic relation.

Fasciculi or Tracts.

As has already been stated, the white matter is somewhat arbitrarily divided into an anterolateral and a dorsal funiculus, and the former again into an anterior or ventral, and a lateral region. Most of the fibres are arranged longitudinally, though some follow an oblique course and the commissural fibres are transverse in direction. Each funiculus is further subdivided into groups of fibres called **fasciculi** or **tracts.**

A fasciculus is a group of fibres having a common origin, a common destination, a common function, and associated in anatomic contiguity. The latter distinction is not always clear, since in some instances tracts are so intermingled as to appear one, though the area may contain several groups having distinct origins, termina-

tions, and functions. Such an area is found in the ventrolateral portion of the lateral funiculus; a large area there was formerly called the **tract of Gowers** and considered as one group of fibres, but is now known to contain several tracts.

The fasciculi have been distinguished one from the others, and their limits determined, by the use of several methods. Waller demonstrated that when a nerve fibre is cut it undergoes a degeneration from the point of severance to its termination but not on the side nearest the cell body, except for a few millimeters. Observation of Wallerian degeneration has aided in delimiting the tracts. Destruction of nerve cells is followed by degeneration of their axons; thus, destruction of ventral horn cells is followed by degeneration of the anterior root fibres, **descending degeneration,** while destruction of spinal ganglion cells is followed by ascending degeneration of dorsal root fibres entering the cord. Certain staining methods in the preparation of the medulla spinalis for histologic examination have been of value, since different tracts react to different stains, showing a chemical difference. Study of the embryonic nerve system has disclosed the fact that different fasciculi develop their medullary sheaths at various stages of development, emphasizing a morphologic separateness.

Fasciculi Proprii.

Surfacing the gray core of the medulla spinalis to varying depths at various parts of its circumference is a layer of white matter known in its entirety as the **fasciculi proprii** or **ground**

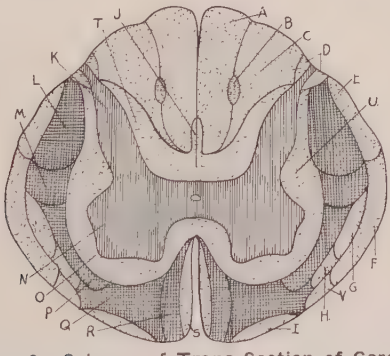

Fig. 6. Schema of Trans-Section of Cord.
AA, Fasciculus Gracilis; B, Comma Fasciculus; C, Fasciculus Cuneatus; D, Lissauer's Fasciculus; E, Dorsal Spinocerebellar Fasciculus; F, Ventral Spinocerebellar Fasciculus; G, Dorsal Spinothalamic Fasciculus; H, Spinotectal Fasciculus; I, Ventral Spinothalamic Fasciculus; J, Septomarginal Fasciculus; K, Dorsal Horn; L, Lateral Cerebrospinal Fasciculus; M, Rubrospinal Fasciculus; N, Ventral Horn; O, Fasciculus Proprius Anterior; P, Tectospinal Fasciculus; Q, Vestibulospinal Fasciculus; R, Ventral Cerebrospinal Fasciculus; S, Sulcomarginal Fasciculus; T, Fasciculus Dorsalis Proprius; U, Fasciculus Lateralis Proprius.

bundles. These consist of fibres which arise in the cells of the gray substance and, after emerging, ascend or descend for a distance before they re-enter the gray; they are associative fibres which serve to establish co-ordination between different levels. Some of these association fibres cross in the anterior white commissure to terminate in the ventral horn cells of the opposite side; most of them end in the ventral horn of the same side; the remainder reach and communicate with cells of the dorsal horn or lateral column.

The fasciculi proprii are separately described in the **three** funiculi; the **fasciculus proprius anterius,** or ventral ground bundle, faces the ventral horn from the line of the most ventral nerve roots to the ventromedian fissure, near which it is somewhat intermingled with the anterior commissure. The **ventral root zone** corresponds to a vertical band covering the emergence of the ventral roots and is thus pierced transversely by these roots. The **fasciculus lateralis proprius** is very thick in the concavity between the ventral and the dorsal cornu and follows both horns more thinly to their extremities. In the dorsal funiculus association fibres are least abundant but there is a narrow **fasciculus dorsalis proprius** facing the gray matter from the tip of the horn to the dorsomedian septum.

Tracts in the Ventral Funiculus.

In addition to the fasciculus proprius anterius the ventral funiculus contains three **descending** and one **ascending** fasciculi.

The **anterior cerebrospinal fasciculus** (*direct pyramidal tract or column of Turck*) lies adjacent to the ventromedian fissure. It is largest in the upper cervical segments and diminishes in size as it descends to disappear as a distinct tract about the midthoracic region. It is small, varying inversely in size with the lateral cerebrospinal tract. The axons of this fasciculus arise in the pre-central area of the cerebral cortex and descend through the brain in common with the fibres which will make up the lateral cerebrospinal until they reach the lower part of the medulla oblongata; there the tract undergoes a partial decussation, the larger part crossing to the opposite side and moving dorsalward as it does so, to occupy a position in the dorsal part of the lateral funiculus. The uncrossed fibres which descend into the cord constitute the anterior cerebrospinal tract. At successive levels of the cord these fibres cross in the anterior white commissure to come into relation with the dendrites of ventral horn cells; they thus become a link in the

direct motor pathway. It is by the successive decussation of groups of axons that the tract diminishes and disappears.

The **vestibulospinal fasciculus** descends throughout the length of the cord to the sacral region. It is concerned with reflexes having to do with the maintenance of equilibrium and derives its axons chiefly from Deiter's nucleus of the same and the opposite side. Deiter's nucleus is the principal terminal nucleus of the vestibular nerve. Some axons are also derived from the medial longitudinal bundle of the medulla oblongata and pons, which have come from scattered cell groups in the formatio reticularis. The vestibulospinal terminal arborizations are related to the motor cells of the anterior column.

The **tectospinal fasciculus** is a tract concerned with visual reflexes, arising in the superior colliculus of the opposite side, decussating in the fountain decussation of Meynert, and descending to divide in the cord and pass down in both the ventral and the lateral funiculi. Its collaterals and terminals end in relation with the motor cells of the anterior horn.

A single ascending tract, the **ventral spinothalamic** lies in the ventral funiculus, at its margin and closely intermingled with the vestibulospinal fibres. Its axons take their origin from cells in the posterior column or intermediate gray matter of the opposite side and cross in the anterior commissure. This tract is supposed to conduct certain tactile impressions to the optic thalamus but its separate existence and identity are somewhat disputed.

Tracts in the Lateral Funiculus.

Descending

- Lateral Cerebrospinal
- Rubrospinal
- Olivospinal

Ascending

- Dorsal Spinocerebellar
- Ventral Spinocerebellar
- Lateral Spinothalamic
- Spinotectal
- Tract of Lissauer

The **lateral cerebrospinal fasciculus** (*crossed pyramidal tract*) is composed of axons arising in the precentral area of the cerebral

cortex. It descends in common with the anterior cerebrospinal fibres through the corona radiata, the knee and anterior two-thirds of the posterior limb of the internal capsule, the middle three-fifths of the crusta of the cerebral peduncle, and the ventral part of the pons. After passing halfway down through the ventral part of the medulla oblongata the major portion of the fibres (*variously stated as from two-thirds to nine-tenths*) cross the median line, turning obliquely backward as they cross, and enter the upper level of the cord in the lateral column just medial to the dorsal spinocerebellar tract and anterior to the posterior gray column. This position is occupied by this tract throughout the length of the cord; it diminishes in size as it descends, by virtue of the fact that at each successive level it gives off groups of axons which come into relation with the motor cells of the anterior horn. This relation is probably not direct, or at least not always direct; there are believed to be intercalated neurons with cells situated in Clark's column or in the base of the posterior column, which receive the terminal cerebrospinal filaments and in turn communicate with ventral horn cells, thus serving to bring the cerebrospinal fibres into control of groups of muscles rather than of individual muscles.

Since the fibres of the lateral cerebrospinal tract decussate in the medulla oblongata and those of the anterior cerebrospinal at various levels of the cord, all the fibres which arise in the motor area of the cerebral cortex ultimately come into relation with lower neuron cells of the side opposite to their origin. The cerebrospinal fibres do not develop medullary sheaths until after birth; when, as a phenomenon of arrested or delayed development, they fail to acquire sheaths within a proper time after birth they do not function properly and a lack of voluntary control of muscles is manifested. These tracts convey voluntary motor impulses and also inhibitory impulses to govern and regulate spinal reflexes which are expressed in the voluntary muscles.

The **rubrospinal fasciculus** (*Prepyramidal tract: tract of Monakow*) is triangular in cross section outline and lies just ventral to the lateral cerebrospinal. Its fibres arise in the cells of the **red nucleus,** situated in the tegmentum of the mid-brain, decussate immediately after leaving the nucleus, and descend throughout the entire length of the cord. Their terminals or collaterals come into direct or indirect relation with the motor cells of the anterior horn. Since the red nucleus receives numerous fibres from the cerebellum through the superior peduncle, this tract is believed to be a part

of the indirect motor pathway especially concerned with cerebellar reflexes and synergic or equilibratory movements of muscles.

The **olivospinal fasciculus** is a little known tract believed to originate in the inferior olivary nucleus in the medulla oblongata and to descend through the cervical cord only, in which it occupies a small triangular area at the margin of the cord in the extreme anterior portion of the lateral column.

The **dorsal spinocerebellar fasciculus** (*direct cerebellar tract of Flechsig*), erroneously termed "cerebellospinal" in the B. N. A., lies at the margin of the lateral funiculus, just external to the lateral cerebrospinal and anterior to the tract of Lissauer. It extends from the level of the second or third lumbar nerve upward through the entire cord and in the medulla oblongata enters the restiform body and reaches the cortex of the cerebellar vermis through the inferior peduncle. It derives its axons from the cells of Clark's column (*dorsal nucleus*) of the same side and increases in size as it ascends by continued accessions of fibres from this source; the axons from Clark's column pass obliquely outward and upward to the margin of the cord and therefore the lower end of the dorsal spinocerebellar tract is slightly higher than the end of the dorsal nucleus. This tract is considered a part of the indirect sensory pathway and is believed to convey impressions of unconscious muscle sense.

The **tract of Gowers** is the name formerly given to the superficial ventrolateral area. This area is now known to be occupied by at least four fasciculi of which one, the ventral spinothalamic, properly belongs to the anterior funiculus while three, the ventral spinocerebellar, the lateral spinothalamic, and the spinotectal belong to the lateral funiculus. The first of the four has already been described.

The **ventral spinocerebellar fasciculus** is apparently continuous at the margin of the lateral funiculus with the dorsal spinocerebellar but differs from it in that its axons are derived from the dorsal and intermediate gray cells of both the same and opposite sides, especially the opposite; these latter cross in the anterior white commissure. The dorsal spinocerebellar tract in transverse section resembles a curved band extending from the tract of Lissauer forward to an imaginary coronal plane drawn through the central canal; the ventral spinocerebellar tract is slightly thickened at its junction with the dorsal and then narrows to a wedge-like

extremity which extends across the root zone into the anterior funiculus.

This is an ascending fasciculus which first appears about the level of the third lumbar nerves and continues upward into and through the medulla oblongata; there a few of its fibres join the inferior peduncle together with those of the dorsal spinocerebellar tract on their way to the cerebellum. It continues through the pons at the edge of the lateral lemniscus and at the level of the inferior colliculus of the mid-brain the major portion of its fibres pass over the superior peduncle and follow its medial border to the cerebellum; the small remainder probably reaches the thalamus. This tract is a part of the indirect sensor pathway. A large part of the fibres decussate in the cord before entering the tract; the remainder probably decussate in the brain.

The **lateral spinothalamic fasciculus,** as its name indicates, is also ascending; it conveys impressions of pain and temperature. It lies just medial to the ventral spinocerebellar and derives its axons from the dorsal nucleus and intermediate gray cells of the opposite side, these having crossed in the anterior commissure. Through the medulla oblongata this tract lies in the formatio reticularis adjacent to the medial lemniscus; it ultimately reaches the ventrolateral region of the thalamus.

The **spinotectal fasciculus** lies ventral to the lateral spinothalamic and somewhat intermingled with it. Its axons arise in the dorsal column. It reaches the medial portion of the lateral lemniscus in the pons and thence passes to the superior colliculi and possibly also to the inferior.

Tracts in the Posterior Funiculus.

The tract of Lissauer, capping the tip of the dorsal cornu, may be described either with the lateral or the dorsal funiculus. The dorsal funiculus is made up of two major fasciculi, the fasciculus gracilis and the fasciculus cuneatus, and the fasciculus dorsalis proprius in which are two special fibre groups called the comma tract and the oval bundle of Flechsig.

The **tract of Lissauer** is possibly composed of dorsal root fibres which here ascend for a short distance before entering the dorsal gray matter, but since this tract does not develop its myelin sheaths until after those of the dorsal root fibres are formed it is more probable that its fibres are intersegmental or associative in

character. It is a slender tract, somewhat tangled with the entering dorsal root fibres at the very tip of the dorsal horn. Undoubtedly this tract is closely associated with the substantia gelatinosa of Rolando, from whose small cells it receives many fibres, probably associative and possibly connected with pain reflexes.

The **fasciculus gracilis** and **fasciculus cuneatus** are in reality one group of fibres derived from the entering dorsal roots of the spinal nerves, but in the cervical and upper thoracic regions they are divided by the postero-intermediate septum; in the medulla oblongata they terminate in separate but adjacent nuclei, the **nucleus gracilis** and **nucleus cuneatus.**

The **fasciculus gracilis** (*tract of Goll*) lies adjacent to the posterior median septum; it is wedge-shaped on transverse section with the broad end of the wedge at the surface of the cord and the tip directed toward the posterior gray commissure. It increases slightly in size from below upward but remains slender throughout, hence its name. Its termination is in the nucleus gracilis of the medulla oblongata to which it conducts impressions of; (a) conscious muscle sense; (b) unconscious muscle sense; (c) impressions of tactile discrimination. From the nucleus gracilis and nucleus cuneatus neurons arise which communicate both with the cerebellum and the thalamus, and through the latter with the cerebral cortex; these will be further described in connection with the medulla oblongata.

The **fasciculus cuneatus** lies lateral to the fasciculus gracilis and is triangular on transverse section. It derives its fibres from the entering dorsal roots and begins at a slightly lower level than its companion tract. Some of the axons of this tract are given to the dorsal gray matter at different levels; others slant medialward to enter and form the fasciculus gracilis; still others ascend as far as the medulla to terminate in the nucleus cuneatus. This tract is thickest in the cervical region, in which region none of its fibres are given to the fasciculus gracilis. Its function is the same in general as that of its companion tract, except for the fibres which enter the dorsal nucleus.

In general the **fasciculus dorsalis proprius** consists of intersegmental fibres arising from cells in the dorsal column and ascending or descending for a short distance before re-entering the gray matter. In the cervical and upper thoracic segments appears the **comma tract of Schultz** in the lateral part of the fasciculus cuneatus, its blunt end toward the gray matter and its tip outward

and backward. It is believed to contain descending branches of entering dorsal nerve fibres, which are to enter the gray matter at a level lower than their entrance into the cord; however, this view is disputed by some who hold that the fibres are intersegmental. The **oval bundle of Flechsig,** in the lumbar region is made up of two halves, one on either side of the median septum, and is also composed of descending intersegmental fibres.

Roots of the Spinal Nerves.

Thirty-one pairs of spinal nerves are attached to the medulla spinalis and each nerve has two roots, a ventral *(anterior, motor, efferent)* and a dorsal *(posterior, sensory, afferent)*.

The **ventral root** is composed of efferent axons arising in the large multipolar cells of the ventral cornu and the smaller cells at the base of the ventral horn and in the lateral column. These fibres at their exit are arranged in from two to four strands for each nerve root and pierce the surface of the cord along its ventrolateral aspect. A line joining the most lateral of these strands marks the division between anterior and lateral funiculi. After their emergence they curve downward, outward and backward to join the dorsal root, which has curved downward, outward, and forward, and the two together constitute a spinal nerve. The ventral root axons acquire myelin sheaths soon after leaving their cell bodies. They serve to convey to the muscles impulses of voluntary motion which have come down from the cerebrum; to the same muscles impulses to involuntary motion which have been aroused reflexly in ventral horn cells by the receipt of afferent stimuli from the periphery; and to involuntary *(visceral)* muscle and secretor epithelium, through the medium of the sympathetic system, impulses which excite the characteristic actions of these organs. Both ventral and dorsal nerve roots become medullated about the fifth month of foetal life.

The **dorsal root** is formed of fibres, both myelinic and amyelinic, which arise in the cells of the spinal ganglia. In the embryo these cells are distinctly bipolar and each presents two processes which proceed from opposite sides of the cell. Later, as the cell grows, it alters its shape, growing chiefly on one side so that the two processes draw nearer together and finally appear to blend and emerge as one. This one divides a short distance from the cell body, making a T-shaped arrangement; the one process extends to the periphery as a sensory nerve fibre where it comes into relation with

special end-organs in skin, muscles, tendons, joints, etc. *(somatic receptors)* or with the sensory end-organs in the viscera *(visceral receptors)*; the other enters the spinal cord. The entering dorsal nerve roots make a series of strands in a vertical line along the dorsolateral sulcus.

Upon entering the cord the dorsal root fibres divide themselves into three groups, a **medial, intermediate,** and **lateral.** The medial group passes directly into the fasciculus cuneatus, the intermediate into the substantia gelatinosa, and the lateral into the tract of Lissauer. All the dorsal root fibres divide into ascending and descending branches after entering the cord, and most of them give off collaterals, smaller in caliber than the fibres from which they spring. Some enter the dorsal nucleus of the same side, some the intermediate gray matter, and some the ventral gray matter of the same side, where they evoke reflex actions. Others cross in the posterior commissure to terminate in relation with the dorsal, intermediate, or ventral gray matter of the opposite side. Those of the intermediate strand largely terminate in the substantia gelatinosa. The descending branches are usually short: some of them form the comma tract, some the oval bundle of Flechsig (*septomarginal tract*), and others are spread through the fasciculus dorsalis proprius. The ascending fibres are longer; some travel upward only 5 or 6 mm. before entering the gray substance, others twice as far, while still others (*the larger fibres*) ascend in the fasciculus cuneatus and fasciculus gracilis to the medulla.

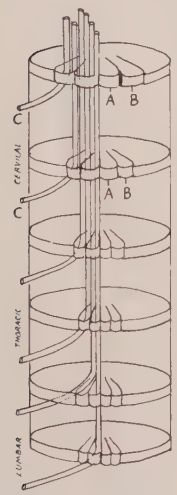

Fig. 7. Relation of Dorsal Root Fibres to Fasciculus Cuneatus and Fasciculus Gracilis in Lumbar, Thoracic, and Cervical Regions. (Schema). AA, Fasciculus Gracilis; BB; Fasciculus Cuneatus; CC, Dorsal Root Fibres.

The relation of the nerve roots to the cuneate and gracile fasciculi is a very exact one. The sacral fibres pass over to the midline and occupy the medial portion of the fasciculus gracilis next to the septum; the lumbar fibres lie external to these, at first in the cuneate and higher up in the gracile fasciculus; the thoracic fibres lie lateral to these and the cervical most lateral of all; the latter never enter the fasciculus gracilis but lie in the fasciculus cuneatus as far as the medulla.

ANATOMY OF THE BRAIN
OR
ENCEPHALON

The **Brain** occupies the cranial cavity and quite closely conforms to its shape. It is by far the largest portion of the nerve system and the most important in that it is the seat of consciousness and volition as well as a governing mechanism for the remaining parts of the nerve system and for the other organs of the body.

In the embryo the cephalic end of the neural tube shows an early advance in development as compared to the remainder, both as to size and complexity of organization. It grows so rapidly and undergoes such infolding and expansion as to lose altogether the appearance of a hollow tube which characterizes the medulla spinalis. The cephalic end of the neural tube early expands into three primary vesicles, each surrounding a dilatation of the canal; the development which takes place in the walls of these three vesicles is in some degree separate from the others and leads to consideration of the brain in its three embryologic divisions, namely, the **hind-brain**, the **mid-brain** and **the fore-brain.**

The hind-brain, or **rhombencephalon** surrounds the **rhomboid fossa**, or **fourth ventricle**, which is an expansion of the central canal of the medulla spinalis; it consists of (a) the **myelencephalon**, including the medulla oblongata and the lower part of the fourth ventricle, (b) the **metencephalon**, including the pons, cerebellum, and the intermediate portion of the fourth ventricle, and (c) the **isthmus rhombencephali**, which immediately adjoins the mid-brain above and includes the superior peduncles of the cerebellum, the upper part of the fourth ventricle, and the anterior medullary velum. It will be seen that the hind-brain is built around the fourth ventricle and that its parts are intimately connected with each other; nevertheless, it will be convenient to study them separately and in turn.

The mid-brain, or **mesencephalon**, connects the fore-brain and hind-brain. It is very small in comparison with the other parts. It is built around the **cerebral aqueduct** *(Aqueduct of Sylvius)* which connects the fourth ventricle below with the third ventricle above and the walls of this canal are thickened to form the **cerebral peduncles** (*crura cerebri*) and the **corpora quadrigemina.**

The fore-brain, **or prosencephalon,** is the part developed from the walls of the most anterior of the three embryonic brain vesicles. The posterior part of this vesicle becomes the third ventricle and from its walls are developed those structures situated at the base of the brain and known collectively as the **diencephalon.** The anterior part of the vesicle develops not into one but into two chambers, the lateral ventricles, around which are grouped the structures of the **telencephalon.**

THE HIND-BRAIN OR RHOMBENCEPHALON

The hind-brain occupies the posterior fossa of the skull and is roofed over, and separated from the cerebrum, by the **tentorium cerebelli,** a fold of dura mater attached to the transverse portion of the crucial ridge of the occipital bone; a look at the interior of the skull will disclose that the entire hind-brain is much less in size than the cerebrum.

THE MEDULLA OBLONGATA.

The medulla oblongata must be considered as the inferior portion of the brain and also as a continuation upward of the medulla spinalis; it is sometimes called "the spinal bulb" because it appears as a bulbous knob at the head of the slender cord. It is located just above the magnum foramen or, to be more exact, above an imaginary transverse plane passing through the middle of the odontoid process of the axis in front and touching the upper border of the atlas behind; at this level the bulb is continuous with the cord. The line of division is somewhat arbitrary, since there is no exact plane at which the internal structures of the one end and those of the other begin. In shape the medulla is an imperfect, inverted, truncated cone or pyramid, with its larger extremity continued into the pons above and its lower end merging into the spinal cord. It is partly embraced from behind and above by the hemispheres of the cerebellum and fits into a valley between them. It helps to form the lower half of the fourth ventricle. In size it measures about 1⅕ in. from above downward, about ⅘ in. from side to side at its widest, and about ½ in. in its greatest antero-posterior dimension. In centimeters it is usually given as 3 cm. by 2 cm. by 1.25 cm. The medulla, like the cord, is bilaterally symmetric.

External Appearance.

In the mid-line anteriorly the medulla presents a deep groove, the **anterior median fissure** *(ventromedian fissure)* lined by a fold of pia mater and extending from the lower border of the medulla to its junction with the pons where the fissure ends in a small enlargement called the **foramen cæcum.** Blood-vessels follow the pia mater into the ventral fissure and thence dip into the substance

Fig. 8. External Appearance of Medulla Oblongata.

of the medulla. The fissure is interrupted in its lower part by intercrossing fibre bundles known as the **pyramidal decussation;** above the decussation some **anterior external arcuate fibres** find their way out of the depths of the fissure and pursue a curving course, upward and lateralward to enter the inferior peduncle. The **posterior median fissure** is seen only in the lower half; it is a shallow groove which grows shallower as it ascends and disappears at the level at which the central canal of the cord becomes dilated to form the fourth ventricle. These two fissures, together with a median raphe which extends from the ventral fissure to the floor

(ventral wall) of the fourth ventricle, divide the medulla incompletely into two symmetric halves. Each half presents on its surface certain structures which appear to be continuous with similar structures in the spinal cord but are only partially so as some rearrangement occurs in the medulla. An **antero-lateral** sulcus, not at all well marked, gives origin to a series of emerging fibre bundles of the hypoglossal or twelfth cranial, nerve which is thus in series with the ventral roots of the spinal nerves. Similarly the eleventh, tenth, and ninth cranial nerves *(accessory, vagus,* and *glossopharyngeal)* enter a postero-lateral sulcus and are in series with the dorsal roots of the spinal nerves. These sulci divide each half of the medulla into an anterior, a lateral, and a posterior area, or are so used for convenience in description.

In addition to the sulci and attached nerve-roots, certain eminences break the regular contour of the medulla. Most anterior of these is the **pyramid,** which lies adjacent to the ventromedian fissure and between it and the antero-lateral sulcus. At its top it is slightly constricted and in the groove thus formed between pons and medulla *(postpontine groove)* the fibres of the abducent nerve emerge. Below the groove the pyramid bulges distinctly, then narrows until it appears to merge into the anterior funiculus of the cord. Actually its structure is quite different from that of the anterior funiculus. The pyramid, as it enters the upper part of the medulla, is made up of cerebrospinal fibres from the pre-central area of the cerebral cortex of the same side; in the lower half of the medulla the major portion of these decussate, crossing the median fissure and curving backward into the lateral area, so that at the lowest level of the medulla the pyramid has been reduced in size by the loss of these crossed fibres to the lateral funiculus. In the cord the crossed fibres constitute the lateral cerebrospinal fasciculus; the uncrossed fibres, which continue in the anterior funiculus near the median fissure, make up the anterior cerebrospinal tract of the cord. The pyramid contains cortico-bulbar fibres which decussate and come into relation with motor nuclei in the medulla, having the same relation to these nuclei as do the cortico-spinal fibres to the ventral gray matter of the cord.

In the upper part of the lateral district, separated from the pyramid by the antero-lateral sulcus and the hypoglossal nerve-roots, is a prominent oval mass called the olive, or olivary body. Below the olive the lateral area of the medulla appears to become continuous with that of the cord but does not actually do so since

only a part of the fibres of the latter are continued into the former. The ventral spinocerebellar fasciculus continues upward through the lateral district of the medulla in much the same position it occupies in the cord, that is, in the ventral margin; the dorsal spinocerebellar tract, on the other hand, bends backward into the posterior district and enters the restiform body. The lateral spinothalamic tract of the cord is similarly placed in the medulla as is the descending rubrospinal tract, but the lateral cerebrospinal tract of the cord only enters the lateral district of the medulla in its lower part, having been previously contained in the pyramid of the anterior district. Most of the lateral area of the medulla is occupied by its fasciculus proprius laterals. The olive is about 1/25 cm. in length. Above it, in a slight depression, are attached the roots of the facial nerve and posterior to them the roots of the acoustic nerve. Altogether the seven last cranial nerves are superficially related to the medulla; the sixth, seventh and eighth along its upper border, or between medulla and pons; the ninth, tenth, and eleventh vertically along the posterolateral sulcus, and the twelfth along the antero-lateral sulcus.

The posterior area of the medulla differs greatly in its lower and upper halves. The interposition of the fourth ventricle just beneath the posterior surface displaces both gray and white matter laterally and brings about a marked change in the relationship of the tracts. In the lower part the fasciculus gracilis and fasciculus cuneatus are continued upward from the cord, the former adjacent to the median fissure and the latter external to the gracilis. Level with the lower end of the ventricle these tracts are forced to diverge laterally and each there presents a bulbous enlargement where it terminates in a nucleus. These nuclei are termed **nucleus gracilis** and **nucleus cuneatus** and they cause curved swelling on the surface of the medulla known as the **gracile** and **cuneate tubercles.** In the lower part of the posterior area of the medulla the substantia gelatinosa produces a third elevation, at first small, but increasing as it ascends until about 1.25 cm. below the pons it becomes the **tubercle** of **Rolando.** Between this elevation and the rest of the medulla lies the spinal root of the trigeminal nerve.

In the upper part of the posterior area lies a thick, cord-like, enlargement called the **restiform body**; in structure, this body is continuous with the **inferior peduncle**, by which name it is best called. The inferior peduncles connect the medulla with the cerebellum. They diverge as they ascend and help to form the lateral

Fig. 9. Coronal Section Through Medulla Oblongata, Showing Opened Fourth Ventricle.

boundaries of the lower half of the fourth ventricle; above this they curve backward, each to its own half of the cerebellum. The inferior peduncle while it appears a continuation of the posterior funiculus of the cord and of the gracile and cuneate fasciculi is actually made up of fibres otherwise derived.

Internal Structure of Medulla Oblongata.

As has already been stated the medulla oblongata must be considered both as a part of the encephalon and as a continuation upward of the spinal cord. The best way to comprehend the rather complicated internal structure of the medulla is to compare it with the relatively simpler arrangement of the gray and white matter of the cord, already described. As in the cord, the gray substance of the medulla is somewhat centrally disposed and is surrounded, through most of its extent, by white matter. Like the white matter of the cord that of the medulla is divided into anterior, lateral, and posterior funiculi. Several fibre tracts connecting the brain with the cord traverse both medulla and cord.

The medulla contains fasciculi proprii like those of the cord adjacent to the gray matter. The bulb contains nuclei of origin and termination for certain of the lower cranial nerves, and its relation to them is similar to that of the cord to the spinal nerves.

Unlike the cord, the medulla is hollowed by the expansion of the central canal into the fourth ventricle. This expansion in its upper half displaces the dorsal gray matter lateralward and forward, causing it to spread out into a more or less flattened mass. The decussation of the pyramids cuts off and displaces part of the ventral horn and the decussation of the lemnisci similarly interrupts the gray matter at a higher level. The medulla is attached to the cerebellum by the inferior peduncles, not duplicated in the cord, and the arrangement of the arcuate fibres of the medulla is unique. The nuclei connected with cranial nerves in the medulla are less regularly disposed than are those of the spinal nerves below; other nerve centers not duplicated in the cord are present. In fact, the medulla presents a much more scattered and varied assortment of nerve cell groups than does its downward prolongation. Finally, certain fibre tracts terminate in the medulla in nuclei from which new axons arise to constitute different tracts. Because of the intimate intermingling of gray and white matter it will be convenient to describe each section of the medulla in its entirety rather than to separate gray and white structures in description.

It should be remembered that only a rough and general outline of the structures of the medulla is practical. If thirty transverse sections be made, at intervals of 1/25 of an inch apart, each section will be found to present points of difference from the others requiring elaborate description. Some important cell groups are very minute in size.

Fig. 10. Drawing of Transverse Section Through Lower Part of Medulla Oblongata, Showing Relation Between Gray and White Matter.
A, Dorsal Gray Matter; B, Ventral Gray Matter.

The **fasciculus gracilis** and **fasciculus cuneatus** which make up most of the posterior funiculus of the cord are continued upward into the medulla and at its lower part fill its posterior area. A little below the middle of the medulla; that is, just below the lower end of the fourth ventricle, these tracts terminate by the arborization of their fibres in relation to the dendrites of cells in the **nucleus gracilis** and **nucleus cuneatus.** The nucleus gracilis is a single mass, quadrangular on transverse section, while the nucleus cuneatus consists of a **medial nucleus,** triangular in shape and larger than its fellow, and a **lateral nucleus** which contains larger cells than the other. From the cells of the gracile and cuneate nuclei new axons arise which form two groups; one group, the **posterior external arcuate fibres,** pass upward into the restiform body and thence to the cerebellum; the other group, directed cephalad, pass forward through the gray column, cutting off the head of the column from its base, decussate with similar fibres from the opposite side, and then run upward in front of the floor of the fourth ventricle and directly behind the cerebrospinal tract, as a flattened band called the **lemniscus** or **fillet.** The crossing of these fibres is known as the **sensory decussation,** or **decussation of the lemnisci.** The lemniscus is joined by the spinothalamic tract, which has already decussated in the cord. It passes upward through pons and mid-brain to terminate in relation to cells in the optic thalamus, from which cells new axons arise to continue the pathway to the sensory area of the cerebral cortex.

The posterior gray matter, at first dorsal to a transverse plane through the central canal, is forced lateralward when the canal expands into the fourth ventricle and the latter extends to the dorsal surface of the cord except for its membranous roof. Here, in the lateral part of the rhomboid fossa, are the nuclei of termination of the sensory components of the vagus and glossopharyngeal nerves, the vestibular portion of the acoustic nerve, and the sensory root of the facial. Above lies the **locus ceruleus,** in which terminate some of the sensory elements of the trigeminal nerve. A long nucleus in which terminate fibres of the spinal tract of the trigeminal is formed by the detached head of the posterior gray column.

In the upper part of the posterior column of the medulla appears a thick, cord-like structure, the **restiform body,** or **inferior peduncle;** it forms at first the lateral wall of the fourth ventricle and then turns abruptly backward to enter the cerebellum between the middle and superior peduncles. The inferior peduncle appears to be a continuation of the dorsal spinocerebellar tract of the cord

but is actually composed of the following groups of axons; (1) the above-mentioned dorsal spinocerebellar tract which ends in the superior cerebellar vermis; (2) fibres from the gracile and cuneate nuclei of the same and opposite sides; (3) fibres derived from the vestibular division of the eighth nerve and from its nuclei of termination; (4) fibres from the olivary nuclei of the opposite side; (5) crossed and uncrossed fibres from the formatio reticularis; (6) probably some fibres from the ventral spinocerebellar fasciculus; and (7) cerebellobulbar fibres, which come from the opposite roof nucleus and dentate nucleus to end in Deiters' nucleus. The inferior peduncle is thus a carrier of a variety of afferent impressions upon which are based those cerebellar reflexes known as equilibratory and which control those co-ordinated movements of the body which serve to maintain its balance under all circumstances. Impressions of muscle sense, tendinous sense, and touch from all levels of the cord and medulla are made available for this purpose as well as impressions from the semicircular canals of the ear by way of the vestibular nerve and nuclei. A few efferent fibres *(cerebellobulbar)* lie in this peduncle but in general it is the great afferent pathway from the general periphery to the cerebellum.

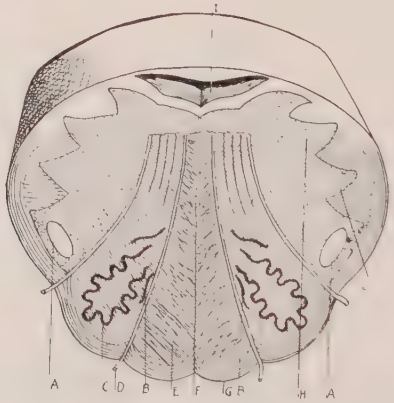

Fig. 11. Transverse Section Through Upper Part of Medulla. A, Ascending Root of Trigeminal n.; B, Accessory Olivary Nucleus; C, Inferior Olivary Nucleus; D, Hypoglossal n.; E, Pyramid; F, Median Fissure; G, Arcuate Fibres; H, Nucleus Gracilis; I, Fourth Ventricle; J, Nucleus Cuneatus.

The **dorsal spinocerebellar fasciculus** enters the lower part of the medulla in its lateral area; thence the major part of its fibres curve backward to enter the inferior peduncle; the remainder join the lemniscus, ascend to the inferior colliculus, decussate, and pass to the cerebellum with the superior peduncle.

The **ventral spinocerebellar fasciculus** enters the ventral part of the lateral column and occupies its periphery until just dorsal

to the olive it passes beneath the external arcuate fibres. It then joins the edge of the **lateral lemniscus** (*derived from the nuclei of the eighth nerve*) and passes through the pons to the mid-brain, where it turns backward to enter the cerebellum along the edge of the superior medullary velum. With the exception of the lateral cerebrospinal tract, which will be described next, the remainder of the lateral area is occupied by the fasciculus lateralis proprius.

The fasciculi proprii of the anterior and lateral columns are so interrupted by scattered masses of gray cells as to form the **formatio reticularis.** The fibres are intersegmental in character; many of them are gathered into a distinct tract called the **medial longitudinal bundle** posterior to the lemniscus and between it and the floor of the fourth ventricle, adjacent to the median raphe. This tract can be traced through pons and mid-brain and is a very important pathway of association for the cranial nerve nuclei.

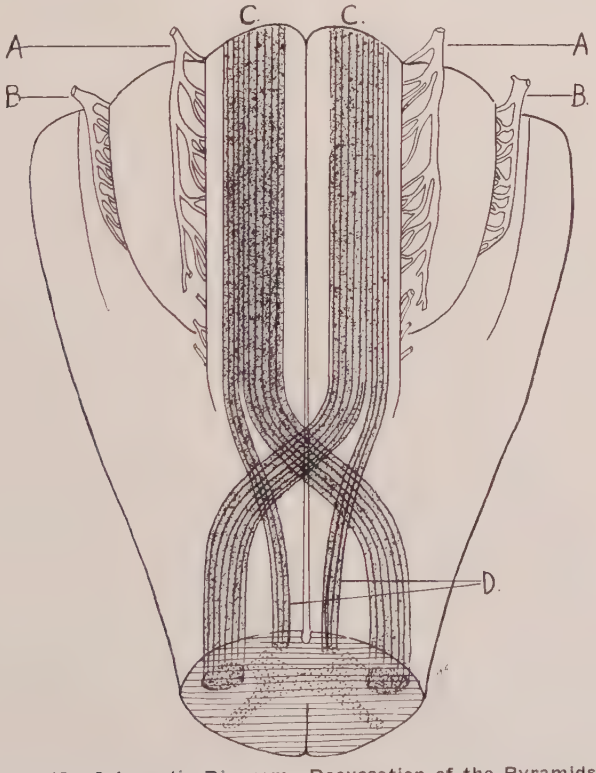

Fig. 12. Schematic Diagram—Decussation of the Pyramids. A, Hypoglossal Nerve; B, Vagus Nerve; C, Undivided Fasciculus Cerebrospinalis; D, Ventral Cerebrospinal Fasciculus.

The **cerebrospinal tract,** as previously described, comes down from the pre-central area of the cerebral cortex, through the corona radiata, the knee and anterior two-thirds of the posterior

limb of the internal capsule, the middle three-fifths of the crusta of the cerebral peduncle, and the ventral part of the pons, giving off fibres in transit to the nuclei of origin of the motor cranial nerves (III, IV, V, VI and VII) and enters the upper part of the medulla, there forming the pyramid. Below the middle of the medulla two-thirds or more of its fibres decussate, crossing the ventromedian fissure and the median raphe, and curve backward into the lateral column where they descend as the lateral cerebrospinal fasciculus. The uncrossed fibres continue to occupy a position adjacent to the ventromedian fissure and in this situation descend the cord as the ventral cerebrospinal fasciculus, giving off fibres at each successive level which decussate in the anterior commissure of the cord and end in relation to its ventral horn cells. This division of the cerebrospinal tract disappears about the mid-thoracic region. The pyramid occupies the major portion of the anterior funiculus of the medulla and the remainder is made up of the fasciculus proprius anterius and the anterior arcuate fibres. The position of the lemniscus is such that it may be described as belonging either to the anterior column or the central area of the medulla.

The **arcuate fibres** are in three groups; (1) the **internal arcuate** fibres, which arise from the gracile and cuneate nuclei and cross to the opposite side to form the larger and deeper part of the inferior peduncle; (2) the **posterior external arcuate fibres,** which arise in the gracile and cuneate nuclei and pass to the inferior peduncle of the same side; (3) the **anterior external arcuate fibres** which follow a peculiar and tortuous course, as follows; they arise from the gracile and cuneate nuclei, pass forward through the formatio reticularis and decussate in the median line, come to the surface in the ventromedian fissure and curve lateralward and backward around the pyramid, cross the olive superficially, and pass backward through the lateral district to reach the inferior peduncle. As they near the olive they are joined by some fibres which emerge between the olive and the pyramid. In front of and medial to the pyramid and enmeshed in the arcuate fibres is a small nucleus, the **nucleus arcuatus**, which contains small fusiform cells which both receive and give off arcuate fibres.

The **olivocerebellar** fibres, from the inferior olivary nucleus to the opposite inferior peduncle, are sometimes also called arcuate fibres. *(anterior internal arcuate fibres.)*

The more important gray masses of the medulla are the nucleus gracilis, nucleus cuneatus, hypoglossal nucleus, nucleus

ambiguus, dorsal motor nucleus, nucleus of the tractus solitarius, and the olivary nuclei. Less important are the numerous scattered masses of cells in the formatio reticularis.

The nucleus gracilis and nucleus cuneatus have already been described. (page 34). They may be regarded as projections of the dorsal gray column of the cord.

The **hypoglossal nucleus,** about 2 cm. in length, lies ventrolateral to the central canal in the lower part but above it approaches the floor of the fourth ventricle where it lies near the middle line under an eminence known as the **trigonum hypoglossi.** Commissural and dendritic fibres connect the two hypoglossal nuclei. The axons of the large multipolar cells of this nucleus make up the hypoglossal nerve; they pass forward between the formatio reticularis alba and the formatio reticularis grisea and emerge from the ventrolateral sulcus.

The **nucleus ambiguus** is a somatic motor nucleus, homologous with the dorsolateral cell group of the anterior column of the cord, from which arise axons distributed as motor fibres through three nerves, glosso-pharyngeal, vagus, and cranial portion of the accessory. This combined nucleus is a slender, elongated column in the deep part of the gray reticular formation, between the dorsal accessory olive and the nucleus of the spinal tract of the trigeminal. It extends from the level of the decussation of the medial lemnisci to the upper end of the medulla. After passing backward toward the floor of the fourth ventricle, its fibres curve lateralward to join sensory fibres connected with the dorsal nucleus.

The **dorsal motor nucleus,** or nucleus ala cinerea, has been called by Malone, "sympathetic or visceral nucleus of the vagus." It is a long column of cells extending from the lower end of the medulla to the level of the oral pole of the inferior olive. Its smaller cells give origin to sympathetic preganglionic fibres to non-striated muscle and its larger cells give off axons which pass by way of the sympathetic to innervate the heart muscle.

The **nucleus of the tractus solitarius** is a slender column of cells extending the entire length of the medulla ventrolateral to the dorsal motor nucleus, its cells lying among and around the fibres of the solitary tract. It is connected with the sense of taste and receives afferent fibres from the facial and glossopharyngeal nerves as well as sympathetic afferent fibres from the vagus. Many of the incoming fibres run for a distance in the solitary tract before terminating.

The **olivary nuclei** are three on either side, the inferior olivary nucleus, the medial accessory olivary nucleus, and the dorsal accessory olivary nucleus. They contain nerve fibres as well as small, round, yellowish cells. The largest, the inferior olivary nucleus, is marked by the surface prominence called the olive; it is a layer of gray substance, infolded from a **hilum** from which springs the **peduncle** of the **olive,** a stalk of olivocerebellar fibres which pass as internal arcuate fibres to the inferior peduncle of the opposite side and thence to the cerebellum. Further connections of the olive are unknown, but it may be connected with the cerebrum and with the spinal cord and may receive fibres from the cerebellum. Experimental destruction of one cerebellar hemisphere results in atrophy of the opposite olive. The **medial accessory olivary nucleus** is a curved lamina, concave laterally, between the inferior olivary nucleus and the pyramid. The **dorsal accessory olivary nucleus** is a smaller curved lamina behind the inferior olivary nucleus.

THE PONS (PONS VAROLII).

The pons is continuous with the mid-brain above and with the medulla below and behind. It is in front of the cerebellum with which it is connected by the middle peduncles *(brachia pontis)*. Its posterior portion forms the upper half of the floor of the fourth ventricle as the medulla forms the lower half. From the upper surface of the pons the cerebral peduncles *(crura cerebri)* ascend, one on either side of the median line: the **tænia pontis** is a white band curving around each peduncle just above the pons and entering the cerebellum between the middle and superior peduncles. The pons is so named because it is a bridge between the other parts of the hind-brain. As compared with the medulla it appears thick and bulbous, especially as viewed from in front.

The **ventral** or **anterior surface** lies upon the sloping clivus of the sphenoid bone and thus occupies the upper ventral portion of the posterior fossa of the skull. It is convex from side to side and slightly less convex from above downward. A vertical groove, the **sulcus basilaris** in the midline receives the basilar artery and marks the division of the pons into symmetric halves. On either side of the sulcus the pons bulges forward

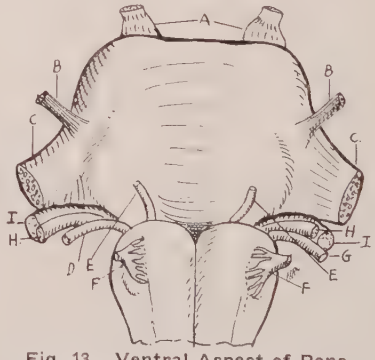

Fig. 13. Ventral Aspect of Pons. A, Oculomotor Nerves; B, Trigeminal n.; C, Middle Cerebellar Peduncles; DG, Acoustic Nerves; E, Abducens Nerve; F, Hypoglossal Nerve; H, Vestibular Nerve; I, Facial Nerve.

where the great cerebrospinal (*pyramidal*) tracts descend. Lateral to these bulges and near the upper border of the pons the trigeminal nerve emerges by two roots, a smaller, medial, motor root and a larger, lateral, sensory root. A vertical line dropped just behind the sensory root of the trigeminal divides the anterior surface of the pons from the beginning of the middle cerebellar peduncle. These peduncles, made up of transverse pontine fibres, emerge from the sides of the pons and sweep lateralward and backward to the cerebellum.

The **dorsal** or **posterior surface** of the pons is a triangular area hidden from view until the cerebellum is removed; it is much smaller than the ventral surface. It is bounded laterally by the middle peduncles and is the part of the pons which helps to form the floor of the fourth ventricle.

Internal Structure of Pons.

On transverse section the pons is seen to be made up of two parts which differ in structure: the **pars basilaris pontis,** or ventral portion, and the **pars dorsalis pontis** *(tegmentum pontis)*, the dorsal portion. The basilar portion is made up largely of nerve fibres arranged in transverse and longitudinal layers and enmeshing small groups of gray cells. The tegmental portion is a continuation of the formatio reticularis of the medulla and contains more gray matter than the basilar portion.

In the basilar portion the nerve fibres are arranged in layers of superficial and deep transverse fibres with longitudinal fasciculi between these layers and somewhat mingled with the deep layer. The **superficial transverse fibres** arise in the nuclei pontis, form a thick layer on the ventral surface, and are narrowed at the side to unite with deep fibres in forming the middle peduncle.

The **deep transverse fibres** lie dorsal to the longitudinal fibres and somewhat mingled with them. They arise in the nuclei pontis and at the sides of the pons join in the formation of the middle peduncle.

The **longitudinal fibres** are cerebropontine, cerebrobulbar, and cerebrospinal tracts known collectively as the pyramidal tracts. They descend from the cerebral cortex through the cerebral peduncles and in the pons cause a considerable forward bulging of the superficial transverse fibres. This great tract above the pons belongs both to the **direct** and **indirect motor pathways.** Some of the fibres come into relation in the pons with the nuclei of origin

of certain motor cranial nerves; viz., the motor root of the trigeminal, the abducent, the facial. This connection is either by means of terminal arborizations, collaterals, or through intercalated associative neurons, the latter method being probably the most common. Such connections make these cortico-pontine neurons links in the direct motor pathway for the conveyance of volitional commands. Similar cortico-bulbar neurons are related to motor nuclei of the hypoglossal and spinal accessory nerve in the medulla and still others descend the cord in the anterior and lateral cerebrospinal fasciculi to establish relationship with the motor nuclei of all the spinal nerves. All the above fibres decussate before entering their terminal nuclei. The fibres of the pyramidal tracts which are a part of the indirect motor pathway terminate in relation to the nuclei pontis, from which new axons arise as transverse fibres of the pons, to be gathered into the middle peduncles and to pass to the cerebellum. From the cerebellum the indirect motor pathway is continued by new neurons which pass by the superior peduncles to the mid-brain and thence, by still another group of neurons, down to and through the spinal cord, chiefly in the rubrospinal tract. The pyramidal tracts are larger and thicker in the pons than in the medulla.

The **nuclei pontis** are scattered groups of nerve cells mingled with the fibres of the pars basilaris pontis. They receive terminal filaments or collaterals from the descending fibres of cortical origin and in turn give off the transverse fibres of the pons. They are serially homologous to the arcuate nuclei of the medulla.

The **dorsum pontis** (*pars dorsalis pontis, tegmentum pontis*) contains the nuclei of the trigeminal, abducent, facial and acoustic nerves, a number of other nuclei which are a continuation of the gray matter of the medulla, and numerous transverse and longitudinal fibres, the latter continuations of fasciculi of the medulla. It is partly divided into halves by a median raphe. In the lower part of the pons the transverse fibres appear as a distinct band, the **trapezoid body,** composed of fibres arising from the cochlear nucleus and at least partly terminating in a nucleus embedded in the trapezoid body, the **trapezoid nucleus.** The chief longitudinal fasciculi are the **medial longitudinal bundle,** an associative tract lying beneath the floor of the fourth ventricle and extending into the mid-brain above and the medulla below, and the **medial lemniscus,** between the formatio reticularis and the trapezoid body. The rest of the tegmentum is a network containing many small masses

of cells, from some of which arise transverse fibres, and the superior olivary nucleus and cranial nerve nuclei mentioned above.

The **superior olivary nucleus** lies above the olivary nucleus on the dorsal aspect of the lateral part of the trapezoid body. It receives some fibres from the trapezoid body. This is much more developed in some animals than in man.

The **nuclei of the trigeminal nerve** in the pons are two, motor and sensory. The **motor nucleus** is near the posterior surface, in the upper part of the pons, and near the lateral margin of the fourth ventricle. Its axons form the motor root of the trigeminal nerve and emerge from the upper ventrolateral surface of the pons; they are joined, after leaving the nucleus, by the descending, or **mesencephalic** root of the trigeminal, which arises from cells beneath the floor of the cerebral aqueduct. The mesencephalic root is believed to be sensory, conveying muscle sense from the temporal, masseter, and pterygoid muscles, but may be motor. The **sensory nucleus** is beneath the superior peduncle and lateral to the motor nucleus. It receives afferent fibres of the trigeminal but not all of them; many descend, as the **spinal tract of the trigeminal nerve** to come into relation with cells of the substantia gelatinosa of Rolando at least as far down as the lower cervical segments of the cord.

The **abducent nucleus** gives origin to the fibres of the sixth cranial nerve. It is a rounded mass of cells, beneath the floor of the fourth ventricle below the medial eminence and above the striae medullares. Its fibres pass forward through the whole substance of the pons medial to the superior olivary nucleus and between strands of cerebrospinal fibres and have their superficial or apparent origin from the groove (*post-pontine groove*) between the medulla and the lower part of the pons. The abducent nucleus receives fibres from the cortex by way of the pyramidal tract.

The **nucleus of the facial nerve** is deep in the formatio reticularis dorsal to the superior olivary nucleus. Its fibres, before emerging from the post-pontine groove, behind the abducent, to form the motor root of the facial nerve, describe within the pons a course comparable to the outline of a bent horseshoe. From the nucleus they pass backward and medialward to the rhomboid fossa, near the median line, where they become a compact bundle; they then pass upward and forward producing a bulge in the floor of the ventricle called the **collicula facialis**, then bend and arch laterally to their point of emergence. This tortuous bend is called the

genu facialis internum to distinguish it from the **genu facialis externum** within the interior of the temporal bone.

The eighth nerve is really made up of two nerves, the cochlear and the vestibular; each has its nuclei of termination in the pons. The cochlear nerve passes to (1) the **lateral cochlear nucleus,** which lies beneath the **tuberculum acousticum** on the dorso-lateral surface of the inferior peduncle and (2) the **ventral** or **accessory cochlear nucleus,** which lies between the two divisions of the nerve on the ventral aspect of the inferior peduncle. The vestibular nerve also passes to two nuclei; (1) the medial **(dorsal or chief vestibular nucleus),** which lies beneath the area acoustica in the lower part of the rhomboid fossa, and (2) the lateral nucleus **(nucleus** of **Deiters)** which is situated at the lateral angle of the rhomboid fossa; the dorso-lateral part of Deiters' nucleus is sometimes separately named **Bechterew's nucleus.**

THE CEREBELLUM.

The cerebellum is the larger part of the hind-brain but much smaller than the cerebrum to which it bears in adult life the proportion of about 1 to 8 in bulk, and in the newborn infant about 1 to 20. It occupies most of the posterior fossa of the skull, behind the pons and medulla, and helps them to form the cavity of the fourth ventricle. It is roofed over by a fold of dura mater, the **tentorium cerebelli,** which separates it from the under surface of the cerebrum and is attached along the transverse portion of the crucial ridge of the occipital bone. The cerebellum is attached to the brain-stem by three pairs of peduncles; to the mid-brain by the superior peduncles (*brachia conjunctiva*), to the pons by the middle peduncles (*brachia pontis*), and to the medulla by the inferior peduncles. In shape it is somewhat oval, flattened from above downward and constricted medially. It is darker in color than the cerebrum and its surface, instead of the irregular cerebral convolutions, shows numerous smooth folds partly separated by curving sulci of varying depths: in general, these sulci seem to parallel each other so as to give an appearance of regularity to the surface, a laminated or foliated appearance.

Divisions of the Cerebellum.

The cerebellum is composed of a middle portion, the **vermis,** smaller than the rest, and two lateral **hemispheres** similar in structure and continuous with each other through the vermis. The vermis is elevated above the remainder of the upper surface and

is there called the **superior vermis;** its under surface is deeply overhung by the hemispheres as a pair of saddle-bags hang from a saddle. The space beneath the vermis and between the hemispheres is the **vallecula cerebelli** and is invaded by the medulla. Below and behind the hemispheres a deep notch, the **posterior cere-**

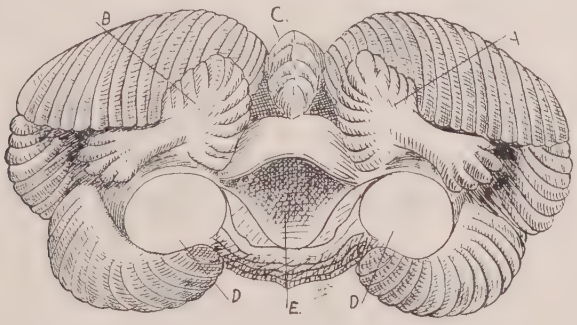

Fig. 14. Cerebellum.
AB, Flocculus; C, Vermis; DD, Brachium Pontis; E, Fourth Ventricle.

bellar notch, divides them; in front, a broader, shallower **anterior cerebellar notch** lies close to the pons and the inferior colliculi. The **falx cerebelli,** a fold of dura mater attached to the lower vertical portion of the crucial ridge of the occipital bone, dips into the upper part of the posterior notch.

Surface of the Cerebellum.

The surface is separated into lobes by the fissures, which penetrate to varying depths and divide the substance of the cerebellum into layers or leaves; each lobe is further subdivided by lesser sulci. Each folium is surfaced by a layer of gray matter and contains white matter internally; the gray matter is chiefly composed of nerve cells and the white matter of nerve fibres. The largest and deepest of all the fissures is the **horizontal fissure** which starts in front of the pons and curves around the middle of each hemisphere in such a way as to divide them into upper and lower parts.

The upper surface is highest in the middle where the superior vermis lies, and slopes toward the circumference. The superior vermis is divided from before backward into the lingula, the lobulus centralis, the monticulus and the folium vermis. With the exception of the lingula, these divisions continue laterally and expand into the lobes of the hemispheres which are, however, differently named. Thus the lobulus centralis is continuous with the alae, the monticulus with the quadrangular lobules, and the folium

vermis with the superior semilunar lobules. The division between the edges of the vermis and the hemispheres is faintly marked by shallow constrictions.

The **lingula,** as its name implies, is tongue-shaped; it is in front of the lobulus centralis and hidden from view. In front it rests upon the anterior medullary velum and the white matter of the one is continuous with that of the other. The lingula has four or five lobules marked by shallow grooves.

The **Lobulus Centralis and Alae.** The lobulis centralis is separated from the lingula, which it overlaps, by the **precentral fissure.** It is a small square lobe in the anterior cerebellar notch. On each side it expands into an ala lobulis centralis.

The **Monticulus and the Quadrangular Lobules.** The largest part of the superior vermis is the monticulus, continuous with the quadrangular lobules of the hemispheres. It is separated in front from the lobulis centralis, which it overlaps, by the **postcentral fissure.** An anterior, elevated part, the **culmen,** is separated from a posterior, slanted part, the **clivus,** by the **preclival fissure.** The culmen monticulus and anterior parts of the quadrangular lobules together make up the **lobus culminis;** the clivus and the posterior parts, the **lobus clivi.**

The **Folium Vermis** and the **Superior Semilunar Lobules.** The folium vermis is a very small, concealed band, posterior to the monticulus; laterally, it expands largely into the superior semilunar lobules so that together they form the **lobus semilunaris.** The semilunar lobules occupy about one-third of the upper surface of the hemispheres and are bounded below by the posterior portion of the horizontal fissure.

The under surface of the cerebellum shows in the middle the **inferior vermis** set off from the hemispheres by deep grooves, the **sulci valleculæ.** From before backward the inferior vermis presents the **nodule,** extended laterally into the flocculus of the hemisphere; the **uvula,** related to the **tonsilla cerebelli;** the **pyramid,** connected with the **biventral lobules;** and the **tuber vermis,** continued into the **inferior semilunar lobules.** The **postnodular,** the **prepyramidal,** and the **postpyramidal** are the three important transverse fissures.

The **Nodule and Flocculus.** The nodule is the anterior end of the inferior vermis and lies against the fourth ventricle. On either side of the nodule and extending to the flocculus is a thin lamina

of white substance, semilunar in shape, and continuous with the white substance of the cerebellum; it is the **posterior** (*inferior*) **medullary velum.** The flocculus is a prominent, irregular lobule, between the biventral lobule and the brachium pontis.

The **Uvula and Tonsilla.** The uvula is divided from the tonsilla of the hemispheres by the sulcus valleculæ at the bottom of which they are joined by a gray band. The tonsils lie in a deep hollow between the uvula and the biventral lobule termed the **bird's nest** (*nidus avis*).

The **Pyramid** and **Biventral Lobules** together make up the **lobus pyramidis.** The pyramid is a large cone-shaped protuberance on the inferior vermis and is connected with the biventral lobules across the sulcus valleculæ by a thin gray band. The biventral lobule is triangular, with base directed forward and apex backward. It is separated from the inferior semilunar lobule behind by the postpyramidal fissure, and from the flocculus in front by the postnodular fissure.

The **Tuber Vermis** and the **Inferior Semilunar Lobules** together constitute the **lobus tuberus.** The tuber vermis is small but the inferior semilunar lobule occupies at least two-thirds of the under surface of its hemisphere.

Internal Structure of the Cerebellum.

The entire surface of the cerebellum is enveloped in a layer of gray matter which dips into the sulci. Enclosed within this layer is a thick core of white matter in the form of a central stem in each hemisphere, from which plates of white matter are projected outward into the folia. Embedded in the central stem of each hemisphere is a considerable gray mass, the **dentate nucleus.** In sagittal section through the middle of the vermis the central stem is seen to divide into a vertical and a horizontal branch, the former ascending to the culmen monticuli and the latter extending backward into the folium vermis; the horizontal branch gives off secondary divisions, one to the clivus monticuli and others to the lobes of the inferior vermis.

The **nucleus dentatus** is a body embedded in the central stem of the hemisphere a little medial to its center. It consists of a thick corrugated envelope of gray matter which enfolds some white matter. The envelope is incomplete at its **hilum,** directed

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medially and upwards, and from this hilum the fibres of the superior peduncle emerge. The dentate nucleus is similar in structure to the inferior olivary nucleus.

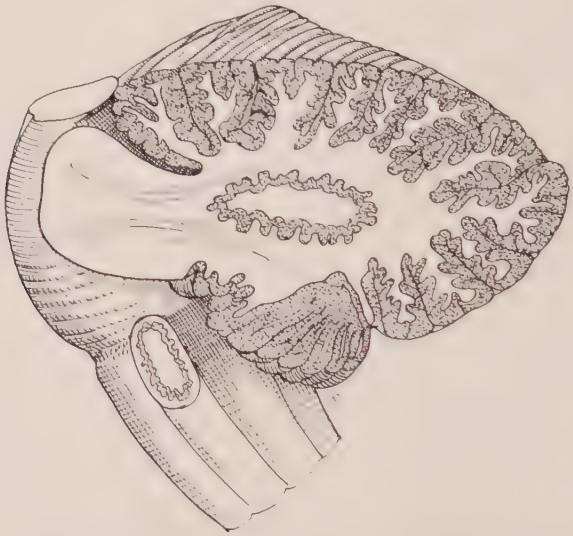

Fig. 15. Drawing of Sagittal Section Through One Cerebellar Hemisphere Showing Relation of Gray and White Matter.

In addition to the nucleus dentatus there are three small masses of gray matter in each hemisphere: the **nucleus embodiformis**, just medial to the hilum of the dentate **nucleus**; the **nucleus globosus** still further medial; and the **nucleus fastigii**, in the vermis near the median plane.

The **white matter** of the cerebellum is made up of **projection fibres and fibræ propriæ.** The projection fibres are those which serve to establish connections between the cerebellum and other parts of the central nerve system. They are in three sets. Those to the mid-brain and cerebrum travel by the superior peduncle; those to the pons traverse the middle peduncle; and those to the medulla go by the inferior peduncle.

The **superior cerebellar peduncles** (*brachia conjunctiva*) are two in number and arise from the medial upper part of the white substance of the hemispheres. As they pass toward the mid-brain they converge slightly and in their course are joined together along their inner edges by the anterior medullary velum. They pass upward as far as the inferior colliculi beneath which they penetrate the substance of the mid-brain. Near their origin they form part of the lateral walls of the fourth ventricle; higher up,

as they converge, they help to form its roof. The fibres contained in the superior peduncle are mainly derived from the cerebellum, but one group, those of the **ventral spinocerebellar tract,** passes to the cerebellum, having ascended from the cord to the mid-brain as previously described. (page 37). The fibres of cerebellar origin arise chiefly in the cells of the nucleus dentatus, though some originate in the three smaller nuclei and some in the cerebellar cortex. They enter the mid-brain and there divide into two groups; the larger group ascends to terminate in the red nucleus, the optic thalamus, and the nucleus of the oculomotor nerve; the smaller group descends into the dorsum pontis. All the fibres from the cerebellum decussate ventral to the Sylvian aqueduct before terminating. The superior peduncle forms a part of the indirect motor pathway, its neurons being the third link in the chain.

The **middle cerebellar peduncles** (*brachia pontis*) are made up of ponto-cerebellar fibres which arise in the nuclei pontis of the opposite side and terminate in the cortex of the cerebellum. They are arranged in three fasciculi, **superior, inferior,** and **deep.** Each middle peduncle arises from the side of the pons and sweeps in a backward curve to enter its corresponding hemisphere. The neurons of the middle peduncles are the second link in the indirect motor pathway, unless it be accepted that the corticopontine fibres which constitute the first link do not terminate directly in relation to the nuclei pontis but in relation to small intercalated neurons (*associative*) which communicate with the pons nuclei; if this be the case then the ponto-cerebellar fibres of the middle peduncles are the third link in the indirect motor pathway and those of the superior peduncles the fourth link.

The **inferior peduncles of the cerebellum** (*restiform bodies*) pass upward and lateralward in the dorsal part of the medulla, forming part of the lateral walls of the fourth ventricle, and then bend sharply backward to reach the cerebellum between the superior and middle peduncles. The groups of fibres in this peduncle have already been named. (page 38).

The **anterior medullary velum** (*valve of Vieussens, superior medullary velum, velum medullare anterius*) is a thin transparent lamina of white substance which extends between the inner edges of the superior peduncles, connecting them. Behind, it is attached to the lingula and folia. It helps to form the roof of the fourth ventricle in its upper part. The **frenulum veli** is a ridge-like projection downward from the inferior colliculi to the velum as it enters

the mid-brain. On either side of the frenulum the trochlear nerve emerges.

The **fibriæ propriæ** of the cerebellum consist of **arcuate** or **association fibres**, which connect adjacent folia with each other, and **commissural** fibres, which cross the median line in the anterior and posterior vermis and serve to bring homologous cortical areas of the two hemispheres into relation with each other.

Structure of the Cerebellar Cortex.

The cortex is a thin envelope of gray matter, quite regularly foliated by a series of fissures each of which gives off secondary fissures; this envelope surrounds the white central mass. A sagittal section through the middle of one hemisphere discloses an outline called the **arbor vitæ** because it resembles a tree; the trunk being represented by the central white stem, the main branches by the major laminæ, and the lesser branches by the secondary folia. The entire arbor vitæ is edged by the gray cortex.

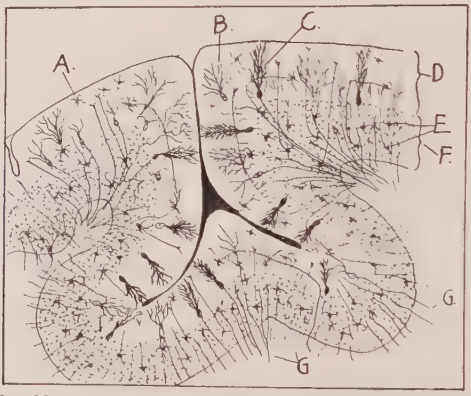

Fig. 16. Microscopic View of Layers of Cerebellar Cortex. (Schema).
A, Molecular Cell; B, Basket Cell; C, Cell of Purkinje; D, External or Gray Layer; E, Granule Cell; F, Internal or Rust-Colored Layer; G, Axons.

Microscopically, the cortex is seen to consist of two layers between which is an incomplete layer containing cells characteristic of this situation, the **cells of Purkinje.** The outer of the two layers is known as the **molecular layer,** the inner as the **nuclear layer.**

The external gray or molecular layer contains both cells and fibres. The cells are small and consist of an outer and an inner stratum; all have branched axons. The cells of the inner layer are the **basket cells** which are laid parallel with the surface and give off collaterals which pass inward to the vicinity of the Purkinjean

cells where they give off basket-like networks of processes. The fibres of the molecular layer are derived from Purkinje's cells, from cells in the nuclear layer, from the central white substance of the cerebellum, and from the cells of the molecular layer itself.

The **cells of Purkinje** make up a single incomplete layer between the molecular and granular layers. They are flask-shaped, bases inward. The axon arises from the base of the flask and passes through the nuclear layer, acquires a medullary sheath and continues into the central white substance. From the neck of the flask arise one or more dendrites which enter the molecular layer and subdivide, the subdivisions further dividing into extended spine-like processes, so as to form a thick bush-like arborescence. This arborescence, seen in section carried parallel to the long axis of the folium, is flattened, while in sections across the folium it is broad and expanded.

The **internal rust-colored** or **nuclear** layer contains many small nerve cells and fibres. The cells are almost spherical and have short dendrites which ramify the nuclear layer in a spidery manner. The axons pass out into the molecular layer and, bifurcating at right angles, run parallel to the surface. There are a few Golgi cells, type II, in the outer part of the nuclear layer.

THE FOURTH VENTRICLE

The **fourth ventricle** (*ventriculus quartus*) is the cavity of the hind-brain, surrounded by hind-brain structures. It is an expansion of the central canal of the cord, with which it is continuous below, and narrows into the mid-brain aqueduct (*aqueduct of Sylvius*) above. It lies in front of the cerebellum and behind the pons and upper half of the medulla. It is lined by ciliated epithelium and filled with cerebrospinal fluid. Its interior is invaginated by the **choroid plexuses.** It presents for examination four **angles,** a **roof,** or dorsal wall, a **floor,** or ventral wall, and two **lateral boundaries.**

Angles. The **superior** angle is at the point of junction between the ventricle and the cerebral aqueduct at the upper border of the pons in the midline. The **inferior** angle is even with the lower border of the olive and marks the junction of the ventricle with the central canal of the cord. Each **lateral** angle marks the point of meeting of the middle and inferior peduncles. Below each lateral angle and level with the striæ medullares is a narrow extension of the ventricle called the **lateral recess.**

Each **lateral boundary** is formed below by the clava, the fasciculus cuneatus, and the restiform body; above the lateral angle by the middle and then the superior peduncle.

Roof. The roof, or dorsal wall, of the fourth ventricle slopes in four directions from a central point toward the four sides of the diamond shaped floor (*rhomboid fossa*). The upper part of the roof is formed by the superior peduncles and the anterior medullary velum, the lower by the posterior medullary velum, the tela choroidea inferior lined by the epithelial lining of the ventricle, the teniæ of the fourth ventricle, and the obex.

The **superior peduncles** emerge from the white substance of the cerebellum and are directed upward and forward so as to form part of the lateral boundaries of the ventricle, but as they approach the mid-brain they converge and form part of the roof. Between the edges of the superior peduncles and filling the angular space between them lies the **anterior medullary velum**, which thus completes the upper half of the roof. The velum is overlapped dorsally by the lingula of the superior vermis.

The **posterior medullary velum** extends from the white substance of the cerebellum downward and forward in front of the nodule and tonsils and ends in a thin concave margin. Below this margin the roof is formed by the epithelial lining of the ventricle, covered and strengthened by a layer of pia mater called the **tela choroidea of the fourth ventricle.** Along the lower lateral boundaries of the ventricle appear two narrow bands of white nerve matter called the **teniæ of the fourth ventricle**, which meet at the inferior angle in a triangular plate, the **obex.**

The **choroid plexuses** are two invaginations of the tela choroidea, covered internally by the epithelial lining of the ventricle, and containing blood-vessels through the walls of which an exchange of materials probably takes place with the cerebrospinal fluid. Each choroid plexus consists of a vertical and a horizontal portion, the former near the median line and the latter extending into the lateral recess.

The **openings in the roof** are three in number, a medial and two lateral; the medial aperture (*foramen Majendii*) is situated just above the inferior angle and opens into the subarachnoid space; the lateral apertures (*foramina of Luschka, foramina of Key and Retzius*) are found one in each lateral recess, at the extremity; they also open into the subarachnoid space and permit an exchange of cerebrospinal fluid between it and the interior of the ventricle.

The Floor of the Fourth Ventricle. The anterior portion of the fourth ventricle is called, from its shape, the **rhomboid fossa,** and the anterior wall is called the "floor" from the fact that in the lower vertebrate animals the brain axis is more or less horizontal. This floor is formed by the back of the pons and of the upper half of the medulla. It is coated with a thin layer of gray matter continuous with that of the spinal cord; the gray matter in this situation is of very great functional importance since here are situated many centers which control the vital processes of the body. The gray matter is surfaced by a thin layer of neuroglia faced by ciliated epithelium and constituting the ventricular ependyma. The rhomboid fossa consists of a **superior** part in the shape of a triangle with its base at the level of an imaginary line drawn through the upper ends of the superior foveæ, its apex at the superior angle, and its sides bounded by the superior peduncles; an **intermediate** part is narrow above between the middle peduncles but widens into the lateral recesses; the **inferior** part is also a triangle with its apex downward to the inferior angle and named the **calamus scriptorius.**

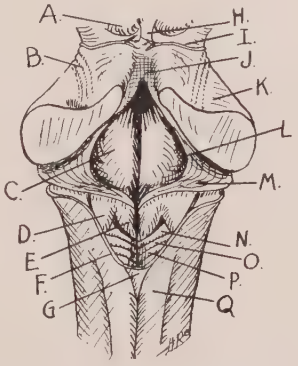

Fig. 17.

Floor of Fourth Ventricle. A, Colliculi; B, Taenia Pontis; C, Colliculus Facialis; D, Ansa Acoustica; E, Trigonum Hypoglossi; F, Taenia of 4th Vent.; G, Obex; H, Frenulum Veli; I, Trochlear n.; J, Anterior Medullary Velum; K, Sup. Peduncle; L, Sup. Fovea.; M, Striae Medullaris; N, Ala Cinerea; O, Funiculus Separans; P, Area Postrema; Q, Clava.

The floor presents numerous elevations and depressions. The **median sulcus** divides it into symmetric halves. On either side of the median sulcus is an elongated prominence called the **medial eminence,** limited laterally by the **sulcus limitans.** In the lower part of the rhomboid fossa the sulcus limitans enlarges into a curved depression, the **inferior fovea;** opposite the collicula facialis it widens into a shallow depression, the **superior fovea;** while in the upper part where it reaches the lateral boundary of the fossa it shows a bluish-gray area, the **locus ceruleus.** Lateral to the foveæ is a rounded eminence, the **area acoustica,** which extends into the lateral recess and there shows a slight swelling called the **tuberculum acousticum.** A number of white fibre bundles, the **striae acousticae,** which are part of the cochlear division of the eighth cranial nerve, wind around the inferior peduncle, cross the medial eminence, and dip into the median sulcus. The **ala cinerea**

marks the location beneath the surface of the sensory nucleus of the vagus and hypoglossal nerves; it is below the inferior fovea and between the **trigonum hypoglossi** and the lower part of the area acoustica.

Within and beneath the floor of the fourth ventricle lie many important nerve cell groups the action and relation of which can only be determined from physiologic experimentation, since it cannot be deduced either from their appearance or their location. These will be studied under "Physiology of the Nerve System." (page 234).

THE MID-BRAIN OR MESENCEPHALON

The **Mid-brain, or Mesencephalon** is a constricted portion of the brain-stem, about three-quarters of an inch in length, which connects the cerebrum above with the pons below. It occupies a notch-like opening in the tentorium cerebelli. From in front the anterior part of the mid-brain can be seen beneath the overhanging fore-brain. The mesencephalon is composed dorsally of four **corpora quadrigemina** or **colliculi** and ventro-laterally of two larger **cerebral peduncles** (*crura cerebri*). It is channeled from below upward by a slender tube, the **cerebral aqueduct** (*aqueduct of Sylvius*), which lies much nearer the dorsal than the ventral surface and connects the fourth with the third ventricle. Around the upper end of each cerebral peduncle winds the optic tract.

Corpora Quadrigemina. The corpora quadrigemina are four rounded eminences, two **colliculi superior** and two **colliculi inferior,** which form the dorsal part of the mid-brain. They are placed below and behind the third ventricle and posterior commissure, above and in front of the superior peduncles and anterior medullary velum. The splenium of the corpus callosum lies above them and the pulvinar of the optic thalamus partially embraces them from the side. On the dorsal aspect of the colliculi is a small oval prominence, the **medial geniculate body.** A crucial sulcus divides the four quadrigeminal bodies; at the upper end of the vertical part of the sulcus is a depression which lodges the **pineal body,** a cone-shaped structure which projects backward from the thalamencephalon and overhangs the superior colliculi.

The superior colliculi are larger than the inferior, somewhat oval in shape, and darker in color; the inferior colliculi are hemispherical and project backward more than the superior.

The **brachia of the corpora quadrigemina** are white bands extending upward and forward, one from each colliculus. From the superior colliculus the **superior brachium** extends lateralward between the pulvinar and the medial geniculate body to pass partly into the optic tract and partly into the **lateral geniculate body.** The **inferior brachium** arises from the inferior colliculus and ascends to disappear under the medial geniculate body. The chief connections of the superior colliculi are with the organs of sight and of the inferior colliculi with the organs of hearing.

The **Cerebral Peduncles.** The cerebral peduncles (*crura cerebri*) are two cylindrical structures constituting the ventral, and larger, portion of the mid-brain. They are partly hidden from view by the overhanging cerebral hemispheres above, but may be viewed from the side by lifting the temporal lobe. The peduncles arise from the pons, diverge as they ascend, and disappear into the base of the cerebrum; between them is a space, the **interpeduncular fossa,** containing a layer of gray matter, the **posterior perforated substance,** foraminated for the passage of blood-vessels; its lower part contains an **interpeduncular ganglion** and its upper part enters into the floor of the third ventricle.

The trochlear nerve crosses the peduncle and the optic tract embraces its upper ventrolateral aspect; the superior cerebellar and posterior cerebral arteries cross the peduncle from medial to lateral side. The medial surface of each peduncle, where it borders the interpeduncular fossa presents a longitudinal groove, the **oculomotor sulcus,** from which the roots of the oculomotor nerve have their superficial origin. A similar groove, the **lateral sulcus,** marks the lateral margin and in this groove the lateral lemniscus reaches the surface to pass backward and upward beneath the inferior colliculus.

Internal Structure of the Cerebral Peduncles. On transverse section each peduncle is seen to consist of a **ventral part** (*base or crusta*) and a dorsal part (*tegmentum*) separated by a layer of dark gray substance, the **substantia nigra.** The tegmenta are joined in the median line but the crusta diverge from each other, so that the mid-brain is wider in front than behind. Dorsally, the corpora quadrigemina are embedded in the tegmenta.

The **crusta,** or base, is made up almost entirely of white fibres arranged in longitudinal bundles. The entire base is semilunar on transverse section. The white fibres belong to three sets; the

cerebrospinal (*including cerebrobulbar*), the frontopontine, and the temporopontine. The **cerebrospinal fibres** are derived from the precentral area of the cerebral cortex and have descended through the corona radiata and the knee and anterior two-thirds of the pos-

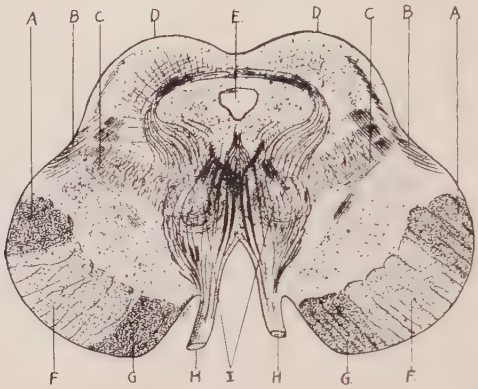

Fig. 18. Drawing of Transverse Section of Mid-Brain, Showing Relation of Gray Matter and of Fibre Tracts.
AA, Temporo-Pontine Tract; B, Lateral Lemniscus; C, Medial Lemniscus; D, Superior Colliculus; E, Cerebral Aqueduct; F, Cerebellospinal Tract; G, Frontopontine Tract; H, Oculomotor Nerve; I, Red Nucleus.

terior limb of the internal capsule. In the peduncle they occupy the middle three-fifths of the crusta, being flanked medially by the frontopontine fibres and laterally by the temporopontine. While traversing the peduncle fibres are given off to the nuclei of origin of the third and fourth cranial nerves and after leaving the peduncle the tract gives off axons to the motor nuclei of the fifth, sixth, seventh, eleventh, and twelfth nerves. The major part of the tract, however, continues into the pyramid of the medulla where two-thirds or more of its fibres decussate with those of the opposite tract to form the lateral cerebrospinal tract of the cord, the remainder continuing down the cord as the ventral cerebrospinal tract. It will be seen that in the mid-brain, as in the internal capsule, the entire group of voluntary motor fibres is compacted into a very closely limited area. The **frontopontine** tract, occupying the medial one-fifth of the crusta, is made up of fibres which arise from the cortex of the frontal lobe of the cerebrum and traverse the mid-brain to reach the nuclei pontis. They are part of the indirect motor pathway—cerebrum to pons, to cerebellum, to mid-brain, to cord. The **temporopontine tract**, likewise part of the indirect motor pathway, arises in the temporal lobe and occupies the lateral fifth of the crusta. Its fibres terminate in the nuclei pontis.

The **substantia nigra** is a lamina of darkly pigmented multipolar cells interposed between the crusta and the tegmentum. On

transverse section its outline is semilunar, with the convexity toward the crusta into which it sends fibres. It extends from the oculomotor sulcus to the lateral sulcus and from the pons to the subthalamic region. The function of the cells of the substantia nigra is not known, though numerous conjectures have been made.

The **tegmentum cruris,** unlike the base of the peduncle, is made up of both gray and white matter, the latter in both transverse and longitudinal fibre bundles; it is continuous with the formatio reticularis of the medulla. The chief cell masses are the red nucleus and the interpeduncular ganglion; the principle fibre tracts are the superior peduncle, the medial longitudinal fasciculus, and the lemniscus.

The **red nucleus** is an important cell station in the indirect motor pathway; it receives many collaterals and terminals from the cerebellum by way of the superior peduncle, and fibres from the ventral longitudinal bundle, Gudden's commissure, and the medial lemniscus. From its cells axons arise which immediately decussate with their fellows of the opposite side and descend as the **rubrospinal tract** in the lateral funiculus of the cord. Other fibres from the smaller cells of the red nucleus terminate in the optic thalamus. The red nucleus is situated in the ventral part of the tegmentum and extends upward into the posterior part of the subthalamic region. At the level of the superior colliculus it is traversed by the fibres of the oculomotor nerve.

The **interpenduncular ganglion** is placed in the mid-line in the ventral part of the tegmentum; it receives fibres from the fasciculus retroflexus of Meynert. Beside the above two nuclei there are other small masses of cells scattered through the tegmentum.

The **superior peduncles** have been described. (page 50.)

The **medial** (*posterior*) **longitudinal fasciculus** is a tract composed of association or intersegmental fibres, both ascending and descending, intimately related to the nuclei of most of the cranial nerves and extending through mid-brain, pons, and medulla to become continuous with the anterior and lateral proper fasciculi of the cord. In the mid-brain it is placed just ventral to the cerebral aqueduct, adjacent to the median line and below the nuclei of the oculomotor and trochlear nerves; in the pons and medulla it runs close to the median line and just beneath the floor of the fourth ventricle. Many of its fibres arise in **Deiter's nucleus** (*lateral vestibular nucleus*) and these fibres, dividing into ascending and de-

scending branches, establish communications by their collaterals and terminals with the motor nuclei of cranial and spinal nerves. Other fibres of this tract are derived from the cells of the formatio reticularis of the medulla, the terminal nucleus of the trigeminal nerve, the superior colliculus, and the posterior commissure. It is believed by some authorities that fibres pass by way of this tract from the nucleus of the abducent nerve to the oculomotor nucleus of the opposite side and thence to the rectus medialis oculi; also fibres from the oculomotor nucleus to the facial nerve and thence to the orbicularis oculi, corrugator supercilii, and frontalis. Certainly this tract is a means whereby extensive communication is established between many cranial nerves and their harmonious action made possible.

The **ventral longitudinal bundle** is largely made up of fibres arising from the superior colliculus, crossing in the **fountain decussation of Meynert,** and descending as the **tectospinal tract.** The fibres mingle more or less with those of the medial longitudinal bundle and the rubrospinal tract. Collaterals and terminals pass to the red nucleus and to the motor nuclei of the spinal cord.

The **medial lemniscus** (*fillet*) has its origin in the gracile and cuneate nuclei of the opposite side. These fibres decussate behind and above the pyramidal decussation in the medulla and continue upward behind the pyramids and between the olives. In the pons and lower part of the mid-brain the medial lemniscus lies close to the median line in the ventral part of the tegmentum; it then moves backward and outward to the dorsolateral part of the tegmentum between the red nucleus and the substantia nigra. In the pons it has a flattened ribbon-like appearance. The lemniscus grows as it ascends by the accession of fibres derived from the various sensory cranial nerve nuclei of the opposite side and terminates in the optic thalamus, where some of its fibres end in the posterior semilunar nucleus but most of them in the principal sensory nucleus. On its way to the thalamus, however, the lemniscus gives off many collaterals to the gray matter of the medulla, pons, and mid-brain; some go to the red nucleus, others to the substantia nigra, and perhaps some to the superior colliculus. Possibly some of the fibres of the lemniscus do not terminate in the thalamus but pass it to reach the lentiform nucleus and the insula; perhaps some others pass through the occipital limb of the internal capsule to reach the cerebral cortex. Certainly most of the fibres terminate in the thalamus, where new axoms arise to complete the direct sensory

pathway by passing to the cerebral cortex in the post-central area. This tract as a whole conveys impressions of conscious muscle sense and of touch and is the direct continuation upward of the posterior funiculus of the cord.

The **central** or **thalamic tract of the cranial nerves** lies on the dorsal aspect of the medial lemniscus and is very closely associated with it. It picks up the spinothalamic tract from the cord and on its way upward grows by accession of fibres from the sensory nuclei of the vagus, glossopharyngeal, facial, trigeminal, and possibly the vestibular nerves. From the terminal sensory nucleus of the trigeminal, fibres cross the median line and form the **central tract of the trigeminal.** Both these tracts give collaterals to the posterior semilunar nucleus of the thalamus and end in the anterior semilunar nucleus.

The **lateral lemniscus** is composed of fibres derived from the terminal nucleus of the cochlear division of the acoustic nerve with some from the superior olivary and trapezoid nuclei; most of its fibres are crossed but some are uncrossed. In the pons it runs along the edge of the medial lemniscus; in the mid-brain it approaches the lateral sulcus and dips under the inferior colliculus. Some of its fibres pass to the inferior colliculus of the same and the opposite side, while others are continued into the thalamus, and thence through the posterior limb of the internal capsule to the cortex of the superior and middle temporal gyri. The lateral lemniscus is concerned with audition and auditory reflexes.

The **cerebral aqueduct** (*aqueduct of Sylvius*) traverses the mid-brain from below upward, connecting the fourth with the third ventricle. It lies between the corpora quadrigemina and tegmenta. It is about 15 mm. in length. Its shape in transverse section varies at different levels, being triangular above and oval in the middle; the central part, slightly dilated, has sometimes been called the ventricle of the mid-brain. The canal is lined with ciliated epithelium and contains cerebrospinal fluid. Immediately anterior to and around the aqueduct is a zone of gray substance containing many small cell masses and the nuclei of three cranial nerves, the oculomotor, the trochlear, and the mesencephalic root of the trigeminal. The latter extends the entire length of the aqueduct; the oculomotor nucleus is about 10 mm. in length; the nucleus of the trochlear is small, circular, and level with the upper part of the inferior colliculus. Ventral to this zone of gray matter lies the

medial longitudinal bundle and the formatio reticularis of the tegmentum; dorsally, it is separated from the quadrigeminal bodies by the lemniscus.

THE FORE-BRAIN OR PROSENCEPHALON

The **fore-brain** is derived from the development of the walls of the most anterior of the three primary brain vesicles. It is by far the largest portion of the brain, filling the anterior and middle fossae of the skull and occupying the entire posterior vault of the cranium above the tentorium cerebelli. From the manner in which the fore-brain develops in the embryo it is somewhat arbitrarily divided into two divisions: the **diencephalon,** which includes the third ventricle and the structures immediately surrounding it; and the **telencephalon,** the cerebral hemispheres. The following outline shows the chief subdivisions of these divisions.

- Diencephalon
  - Thalamencephalon
    - Thalamus
    - Metathalamus
    - Epithalamus
  - Pars mammillaris hypothalami
  - Posterior part of third ventricle
- Telencephalon
  - Cerebral Hemispheres
    - Rhinencephalon
    - Corpus Striatum
    - Neopallium
  - Pars optica hypothalami

DIENCEPHALON

The diencephalon lies directly above the mid-brain and appears completely embedded in the under part of the overhanging cerebral hemispheres. It is covered above by the corpus callosum from which it is separated by the **tela choroidea of the third ventricle,** a fold of pia mater. The diencephalon is organized around the **third ventricle;** it is composed of the thalamencephalon, the pars mammillaris hypothalami and the posterior part of the third ventricle. Embryologically, the anterior part of the third ventricle and the related pars optica hypothalami, belong to the telencephalon but they are more conveniently described with the remainder of the third ventricle.

Thalamencephalon. This subdivision of the diencephalon is made up of, (a) the **thalamus,** (b) the **metathalamus** or **corpora**

geniculata, and (c) the **epithalamus,** which includes the trigonum habenulae, the pineal body, and the posterior commissure.

Thalamus. The optic thalami are two large oval masses placed on either side of the third ventricle but extending for some dis-

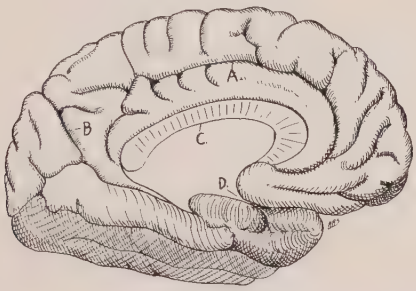

Fig. 19. Drawing of Sagittal Section of Cerebrum.
A, Cingulate Sulcus; B, Parieto-Occipital Fissure; C, Corpus Callosum; D, Uncus.

tance posterior to that cavity. Each is about 4 cm. in length and presents for examination an anterior and a posterior extremity and four surfaces, superior, inferior, medial, and lateral.

The **anterior extremity** is narrow, lies close to the mid-line, and forms the posterior boundary of the interventricular foramen.

The **posterior extremity** extends backward and lateralward so as to overhang the superior colliculus; it is much wider than the anterior. The **pulvinar** is an angular prominence of the medial aspect of the posterior part of the thalamus; lateral to the pulvinar is an oval enlargement, the **lateral geniculate body;** beneath the pulvinar but separated from it by the superior brachium, is the **medial geniculate body.**

The **superior surface** is convex and is surfaced by a layer of white matter called the **stratum zonale.** Laterally it is limited by a white band, the **striae terminalis** and by the terminal vein; beyond these lateralward lies the caudate nucleus. A shallow oblique furrow divides this surface into a medial and a lateral area; the lateral area forms part of the floor of the lateral ventricle and is covered by the epithelium lining that cavity; the medial part has no epithelial covering but is covered by the tela choroidea of the third ventricle. In front, the medial and superior surfaces are separated by an edge, the **taenia thalami.**

The **inferior surface** is continuous with the upward prolongation of the tegmentum, upon which it rests and anteriorly is related to the **substantia innominata of Meynert.**

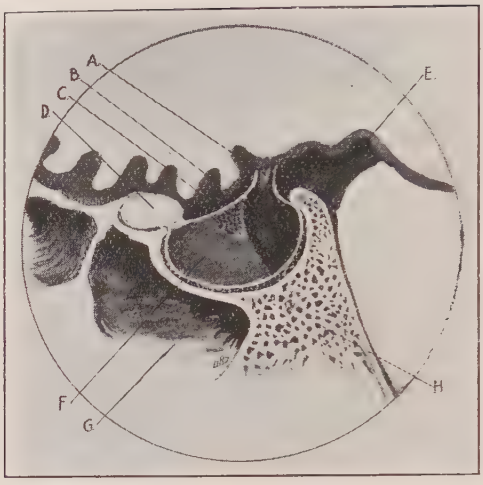

Fig. 20. Hypophysis Cerebri.
A, Infundibulum; B, Dorsal Lobe; C, Intermediate Lobe; D, Optic Chiasma; E, Dorsum Sellae; F, Anterior Lobe; G, Sphenoidal Sinus; H, Sphenoid Bone.

The **medial surface** forms the upper part of the lateral wall of the third ventricle. It is connected across the mid-line with the opposite thalamus by the **massa intermedia** (*middle or gray commissure*) which is about 1 cm. in antero-posterior diameter. This contains nerve cells and nerve fibres, some of which cross the middle line but most of which approach it and then curve away on the same side.

The lateral surface is adjacent to the occipital part of the internal capsule and to the lentiform nucleus.

Structure of the Thalamus. The thalamus is largely made up of gray matter arranged in nuclei; it is a great ganglion. However, the gray matter contains many nerve fibres and there are several distinctly white bands of fibres, such as the stratum zonale, already mentioned, the **lateral medullary lamina**, and the **medial medullary lamina**, which partly subdivides the gray matter into anterior, medial, and lateral divisions. Between the two medullary laminae lies the pulvinar, the largest part of the thalamus. The lateral portion of the gray matter is traversed by many fibres which pass from the thalamus to the cerebral cortex by way of the internal capsule.

Connections of the Thalamus. The thalamus is chiefly a sensory ganglion. It receives from below the lemniscus and the spino-

thalamic tracts, which convey to it impressions of touch, pain, and temperature, as well as conscious muscle and tendon sense. The thalamic cells give off new axons (*thalamo-cortical*) which complete the direct sensory pathway by conveying to the post-central area of the cerebral cortex the impressions derived from the lemniscus. Many fibres from the optic tract terminate in the posterior part (*pulvinar*) of the thalamus; at its anterior tubercle enters the **thalamomammillary fasciculus** (*bundle of Vicq d'Azyr*), from the corpus mammillare. Cortioco-thalamic fibres enter in large numbers.

The existence of a **thalamospinal tract** is in doubt. The thalamus gives off fibres to the cerebral cortex in four chief groups, or stalks; (1) the **anterior stalk** passes through the frontal limb of the internal capsule and radiates in the frontal lobe; (2) the **posterior stalk** (*optic radiation*) arises in the pulvinar and passes through the posterior part of the posterior (*occipital*) limb of the internal capsule to the cortex of the occipital lobe; it is concerned with vision; (3) the **inferior stalk** arises from the under and medial surfaces of the thalamus and passes underneath the lentiform nucleus to reach the insula and the cortex of the temporal lobe; (4) the **parietal stalk** leaves the lateral nucleus of the thalamus and goes to the surface of the parietal lobe. In addition to these groups, fibres connect the thalamus with the caudate and lentiform nuclei, the former from the lateral thalamic surface and the latter from the inferior.

The **Metathalamus** is made up on each side of the two **geniculate bodies—a lateral and a medial.**

The **medial geniculate body** (*internal geniculate body, corpus geniculatum mediale*) is situated lateral to the superior colliculus and beneath the pulvinar of the optic thalamus, from which it is separated by the superior brachium. It is oval in shape with its long axis directed forward and lateralward. It is smaller and lighter colored than the lateral. The two medial geniculate bodies are connected across the mid-line by **Gudden's commissure,** which contains fibres passing in both directions. The medial geniculate body receives acoustic fibres from the lateral lemniscus and gives a strand of fibres to the optic tract. Its chief connection is believed to be with the function of audition.

The **lateral geniculate body** (*external geniculate body, corpus geniculatum laterale*) appears as a tumefaction on the lateral and inferior aspect of the pulvinar; it connects by the superior brach-

ium with the superior colliculus. It is made up of alternating layers of gray and white matter which give it a dark color and a laminated appearance. It receives many fibres from the optic tract while other optic fibres traverse it on their way to the pulvinar. Its cells give off axons which pass to the visual area of the occipital cortex.

The **Epithalamus** is made up of the **trigonum habenulae**, the **pineal body**, and the **posterior commissure.**

Lateral to the posterior part of the taenia thalami and in front of the superior colliculus is a small depressed triangular area, the **trigonum habenulae**, containing a group of nerve cells, the **ganglion habenulae.** It receives fibres from the pineal body and from the opposite habenular ganglion by the **habenular commissure.** Most of its outgoing fibres are gathered into the **fasciculus retroflexus of Meynert**, which passes downward medial to the red nucleus, decussates with the corresponding fasciculus from the opposite side, and ends in the interpeduncular ganglion.

The **pineal body** is a small, conical, reddish-gray structure with its base directed forward and its attachment by a stalk of white fibres. It lies between the superior colliculi and beneath the splenium of the corpus callosum, from which it is separated by the tela choroidea of the third ventricle. It measures about 8 mm. in length.

The **posterior commissure** is a transverse band of white fibres, found in sagittal section, which crosses dorsal to the upper end of the cerebral aqueduct. Most of its fibres originate in the **nucleus of the posterior commissure** in the central gray substance at the upper end of the aqueduct; some probably come from the thalamus and from the superior colliculus. There is probably a connection with the medial longitudinal bundle.

The **Hypothalamus** includes the **subthalamic tegmental region**, and those structures which form most of the floor of the third ventricle; namely, the **corpora mammillaria, tuber cinereum, infundibulum, hypophysis**, and **optic chiasma.**

The **subthalamic tegmental region** is an upward continuation of the tegmentum of the mid-brain; it lies ventro-lateral to the thalamus which it separates from the fibres of the internal capsule. The red nucleus and the substantia nigra extend into its lower part.

Medially it is in contact with the gray matter of the floor of the third ventricle and anteriorly with the substantia innominata of Meynert. From above downward it is composed of three strata: (a) the **stratum zonale**, directly attached to the under surface of the thalamus; (b) the **zona incerta**, a continuation of the formatio reticularis of the mid-brain; (c) the **corpus subthalamicum** (*nucleus of Luys*), an encapsulated lentiform mass of nerve cells situated on the dorsum of the basilar fibres of the cerebral peduncle.

The **corpora mammillaria** (*corpora albicantia*) are two round white masses, each the size of a small pea, placed below the gray

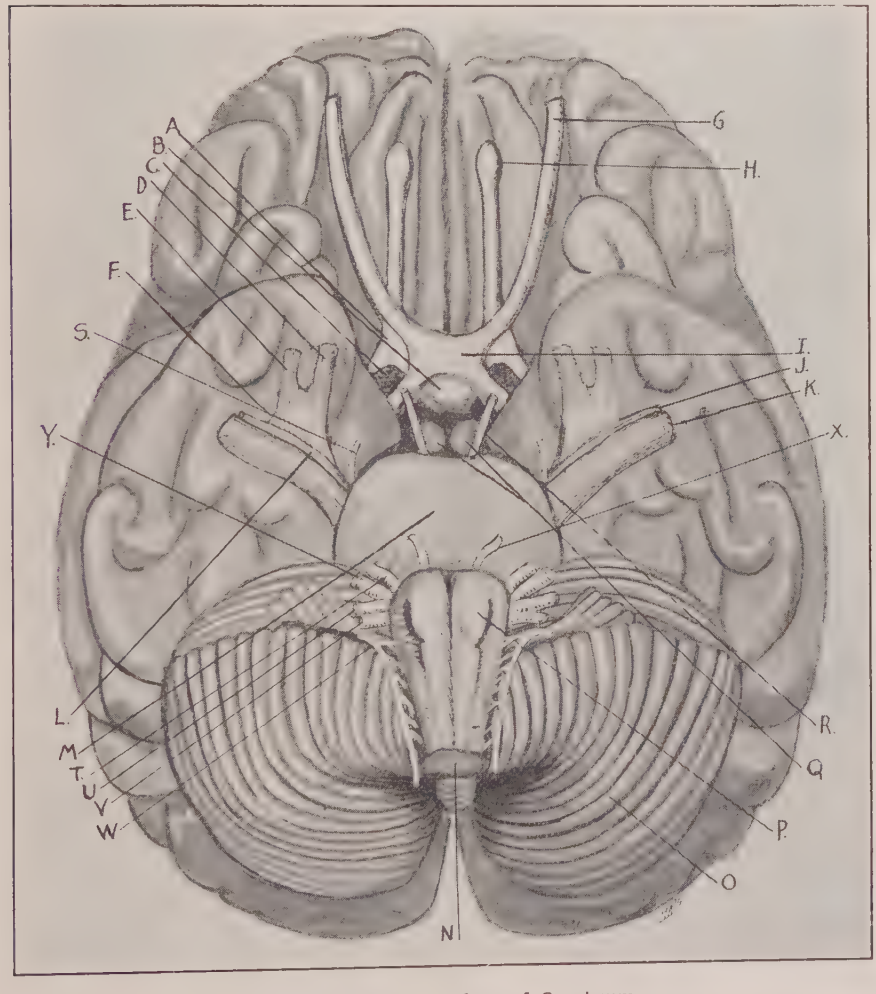

Fig. 21. Under Surface of Cerebrum.
A, Olfactory Trigone; B, Hypophysis; C, Anterior Perforated Substance; D, Ophthalmic Nerve; E, Maxillary Nerve; F, Gasserian Ganglion; G, Optic Nerve; H, Olfactory Bulb; I, Optic Chiasma; J, K, L, Mandibular Nerve; M, Pons; N, Medulla; O, Cerebellum; P, Olive; Q, Mammillary Bodies; R, Oculomotor Nerve; S, Trochlear Nerve; T, Facial Nerve; U, Glossopharyngeal Nerve; V, Vagus Nerve; W, Accessory Nerve; X, Abducens Nerve; Y, Acoustic Nerve.

floor of the third ventricle in front of the posterior perforated substance. They are made up of white matter externally and gray internally, the latter in two nuclei, a medial and a lateral. The white fibres are derived from the columns of the fornix and from the medial lemniscus. Each mammillary body gives origin to a thalamomammillary fasciculus (*bundle of Vicq d'Azyr*) which passes to the anterior nucleus of the thalamus, and to a descending fasciculus which passes downward in the tegmentum.

The **tuber cinereum** is a hollow prominence of gray matter between the optic chiasma in front and the corpora mammillaria behind. From its under surface an **infundibulum** extends downward and forward to the posterior lobe of the hypophysis.

The **hypophysis** (*pituitary body*) is a bilobed, reddish-gray mass about 12.5 mm. transversely and about 8 mm. in its anteroposterior dimension. It is lodged in the fossa hypophyseos (*sella turcica*) of the sphenoid bone and roofed in by a fibrous membrane, the **diaphragma sellae**, except where that membrane presents an opening for the reception of the infundibulum. The anterior lobe is nervous in structure, the posterior glandular.

Optic Chiasma (*optic commissure*). The optic chiasma is a flattened quadrilateral band of fibres which rests upon the chiasmatic groove of the sphenoid bone and corresponds in position to the junction of the floor with the anterior wall of the third ventricle. It is above and in front of the hypophysis. At its anterolateral angles it receives the **optic nerves** and from its posterolateral angles it gives off the **optic tracts.** Most of its fibres come from the optic nerves, but in the posterior part of the commissure lies a curving band, **Gudden's commissure,** which is a pathway of communication between the two medial geniculate bodies. The optic fibres undergo partial decussation in the chiasma; those from the nasal half of each retina cross with those from the opposite side, the decussation occupying the middle portion of the chiasma; those from the temporal halves of the retinae occupy the lateral portions and continue backward in the optic tracts undecussated. It follows therefore that each optic tract contains fibres from both retinae, from the temporal half of one and the nasal half of the other. The optic tract carries impressions from one-half the field of vision while the optic nerve carries impressions from one entire retina.

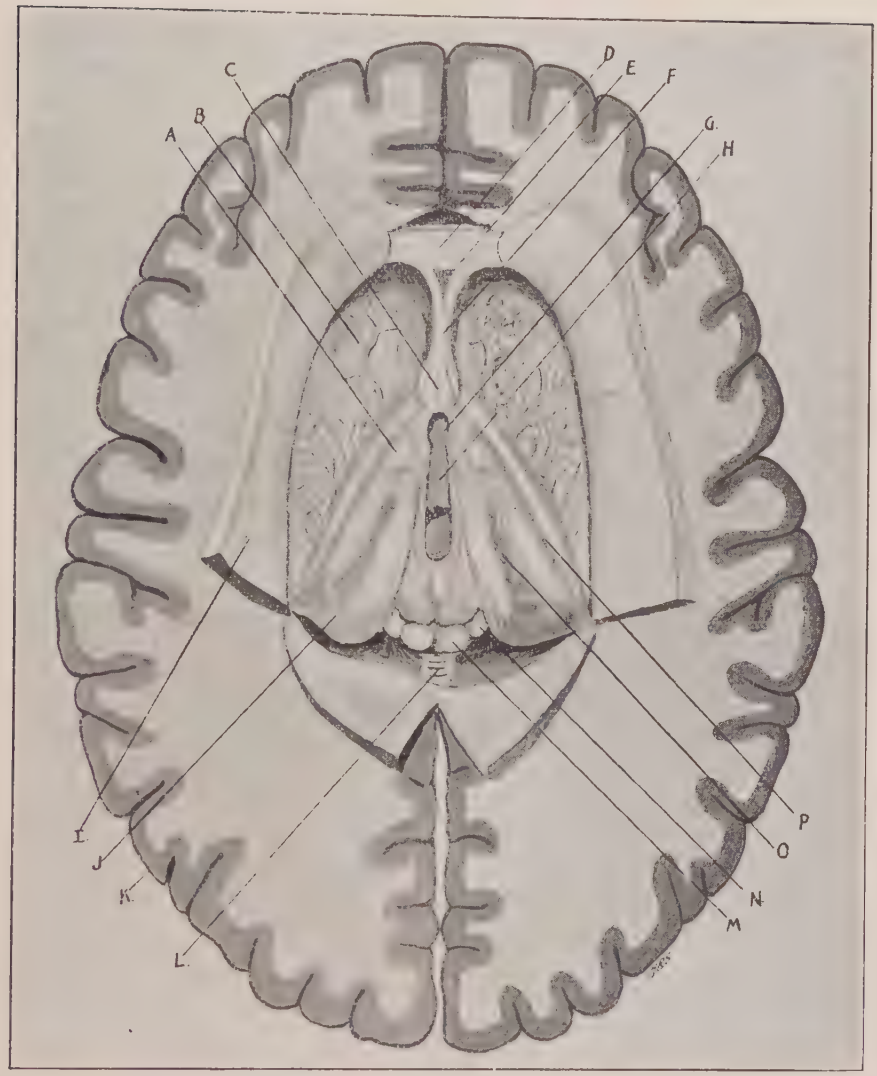

Fig. 22. Transverse Section Through Cerebrum at Level of Optic Thalamus.
A, Thalamic Tubercle; B, Lateral Ventricle; C, Columns of Fornix; D, Genu of Corpus Callosum; E, Cavum Septi Pellucidi; F, Septum Pellucidum; G, Third Ventricle; H, Massa Intermedia; I, Corpus Callosum; J, Pulvinar; K, Cerebral Cortex; L, Lingula; M, Superior Colliculi; N, Inferior Colliculi; O, Thalamus; P, Stria Terminalis.

Optic Tracts. From the postero-lateral angle of the chiasma the optic tracts continue backward and lateralward between the anterior perforated substance and the tuber cinereum, wind around the ventrolateral aspect of the cerebral peduncle and divide each into a medial and a lateral root. The medial root contains the fibres of Gudden's commissure, which terminate in the medial geniculate body. The lateral root contains a few efferent fibres from cerebrum

to retina but is chiefly composed of afferent fibres which have arisen in the ganglionic layer of the retina; these fibres terminate in the lateral geniculate body, the pulvinar of the optic thalamus, and the superior colliculus and these three organs are therefore called the **lower visual centers.** From these centers new axons arise which continue the visual pathway through the **optic radiations** which pass through the posterior portion of the occipital limb of the internal capsule and thence proceed to that cortical area, in the occipital lobe of the cerebrum, known as the **higher** or **cortical visual center.** The radiations also contain some fibres from the cortical centers to the lower visual centers. Some fibres leave the optic pathway to descend in the cerebral peduncle to the oculomotor nucleus; these are believed to be afferent fibres for the Sphincter Pupillae and Ciliaris muscles.

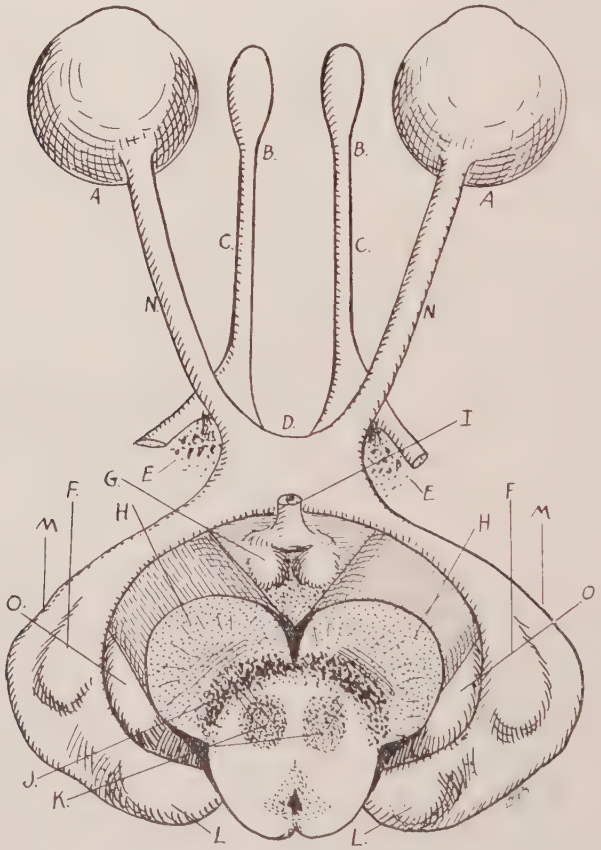

Fig. 23. Optic Pathway.
A, Bulbus Oculi; B, Olfactory Bulb; C, Olfactory Tract; D, Optic Chiasma; E, Anterior Perforated Substance; F, Lateral Geniculate Body; G, Mammillary Bodies; H, Cerebreal Peduncles; I, Stalk of Hypophysis; J, Substantia Nigra; K, Red Nucleus; L, Pulvinar of Optic Thalamus; M, Optic Tract; N, Optic Nerve; O, Medial Geniculate Body.

The **Third Ventricle,** a narrow slot between the two thalami, is the cavity around which the diencephalon is organized. It is connected behind with the cerebral aqueduct and thus with the fourth ventricle; in front it opens into the lateral ventricles by the **interventricular foramen.** It is somewhat triangular with the apex directed backward, and has a roof, a floor, an anterior and a posterior boundary and two lateral walls.

The **roof** is a layer of epithelium continuous with the lining of the ventricle and above and adherent to this layer is a layer of pia mater, the **tela choroidea of the third ventricle.** A pair of highly vascular processes, the **choroid plexuses of the third ventricle,** extend downward from this roof and invade the cavity.

The **floor rests,** from before backward, on the optic chiasma, tuber cinereum, infundibulum, and corpora mammillaria, and back of the latter on the interpeduncular fossa and the tegmentum. The interior of the infundibulum is hollowed by an extension of the ventricle into the **recessus infundibuli.**

The **anterior boundary** is formed above by the anterior commissure and the columns of the fornix, below by a thin layer of gray matter extending between the rostrum of the corpus callosum and the upper surface of the optic chiasma and called the **lamina terminalis.**

The **posterior boundary** consists of the pineal body and the posterior commissure. To it the cerebral aqueduct is connected. A small diverticulum, the **recessus pinealis,** extends into the pineal stalk.

Each **lateral wall** is formed in its lower part by an upward prolongation of the gray substance of the ventricular floor. Above, the anterior two-thirds of the thalamus walls in the ventricle. The **sulcus of Monro** separates these two parts, which are formed respectively from the basal and alar laminae of the lateral wall of the fore-brain vesicle. Across the ventricle, the lateral walls are joined by a gray band, the **massa intermedia.** The columns of the fornix curve downward in front of the interventricular foramen and then turn backward along the lateral walls where they give rise to prominences on the interior of the ventricle.

The **interpeduncular fossa** is a lozenge-shaped area bounded in front by the optic chiasma, behind by the upper part of the pons, and laterally in front by the optic tracts and behind by the cerebral

peduncles. It contains from behind foreward the posterior perforated substance, corpora mammillaria, tuber cinereum, infundibulum, and hypophysis.

THE TELENCEPHALON

Developmentally, the telencephalon includes the **pars optica hypothalami** and the anterior part of the third ventricle, which

Fig 24. Fissures of Upper Surface of Cerebrum.
A, Central Sulcus; B, Superfrontal Sulcus; C, Frontocentral Sulcus; D, Longitudinal Fissure.

have been described with the diencephalon. The major part of the telencephalon, still to be described, is composed of the two **cerebral hemispheres.**

The **Cerebral Hemispheres.** Each hemisphere is made up of three parts: the **rhinencephalon,** the **corpus callosum,** and the **neopallium.** Of these, the rhinencephalon, which is the part of the brain related to the sense of smell, is the oldest; in some of the lower animals it comprises most of the hemisphere. In man it is relatively small and is completely over-shadowed by the growth of the neopallium, which makes up by far the greater part of the hemisphere.

Viewed from above the cerebral hemispheres together are ovoid in shape, broadest between the two parietal eminences but greater in the antero-posterior than in any transverse diameter. The hemispheres are separated in the median line by a deep cleft, the **longi-**

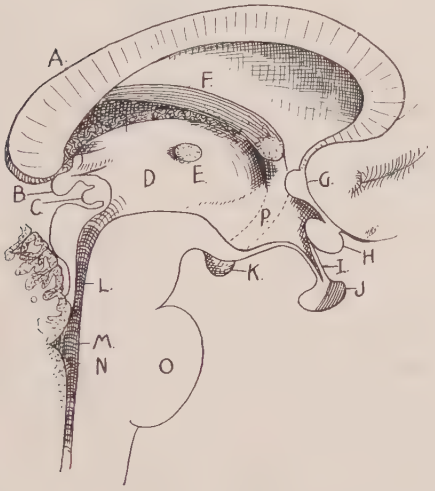

Fig. 25. Drawing of Sagittal Section Through Longitudinal Fissure.
A, Corpus Callosum; B, Pineal Body; C, Dorsal Commissure; D, Third Ventricle; E, Middle Commissure; F, Fornix; G, Anterior Commissure; H, Optic Chiasma; I, Stalk of Hypophysis; J, Hypophysis; K, Mammillary Bodies; L, Cerebral Aqueduct; M, Fourth Ventricle; N, Central Canal; O, Pons; P, Column of Fornix.

tudinal cerebral fissure. This fissure extends entirely through the hemispheres from the upper to the under surface in front and behind but the middle of the fissure divides them for only about one-third of their vertical extent; there an arched transverse band, the **corpus callosum,** connects the hemispheres across the mid-line and interrupts the fissure. Into the depths of the fissure dips a fold of dura mater in the shape of a sickle, the **falx cerebri.** Lining the fissure and surfacing the hemispheres is the pia mater.

The **corpus callosum,** in a section parallel with the longitudinal fissure, shows itself as a broad arched band of white matter. It

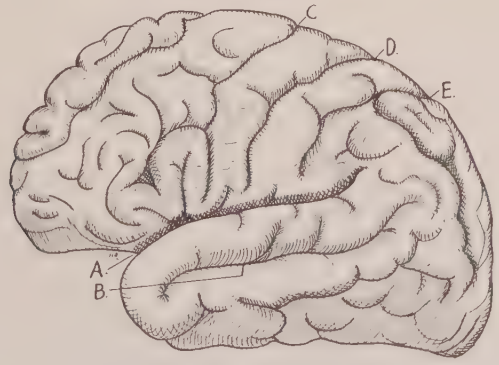

Fig. 26. Fissures of Lateral Surface of Cerebrum.
A, Lateral Fissure; B, Superior Temporal Sulcus; C, Paracentral Sulcus; D, Central Sulcus; E, Intraparietal Sulcus.

is made up of commissural fibres transversely arranged. At the posterior extremity the **splenium** is a thick bulbous mass overhanging the mid-brain but separated from it by the pineal body and the tela choroidea of the third ventricle. The anterior end of the corpus callosum is curved into the **genu,** which tapers into a thinner portion, the **rostrum,** which extends downward and turns backward in front of the anterior commissure to connect with the lamina terminalis. Somewhat parallel with the corpus callosum but underneath it, extending from just behind the anterior commissure to the under side of the splenium, is a second arched band, the **fornix.** Between the corpus callosum and the fornix are the walls and cavity of the septum pellucidum.

Surfaces of the Hemisphere. Each hemisphere has three surfaces: **medial, lateral,** and **inferior.** The medial surface is relatively flat and is apposed to the medial surface of the opposite hemisphere from which it is separated by the longitudinal fissure and the falx cerebri. The lateral surface is largest in area by virtue of its convexity; it fits into the concave vault of the cranium. The inferior surface is very irregular and is divided into three areas which correspond with the three cranial fossae: an anterior, a middle, and a posterior. The anterior area is formed by the concave orbital surface of the frontal lobe and rests upon the bony roof of the orbit and of the nose; the middle area is the convex under surface of the temporal lobe and occupies half the middle cranial fossa; the concave posterior area rests upon the tentorium cerebelli and is called the **tentorial** surface; its concavity is directed medialward as well as downward.

The **borders** between these three surfaces are:

1. **Supero-medial,** between medial and lateral surfaces.

2. **Infero-lateral,** between lateral and inferior surfaces; that part of this border which separates the lateral from the orbital surface is called the **superciliary border.**

3. **Medial occipital,** between the medial and tentorial surfaces.

4. **Medial orbital,** between orbital and medial surfaces.

The anterior end of the hemisphere is called the **frontal pole;** the posterior end, the **occipital pole;** and the anterior end of the temporal lobe, the **temporal pole.** The **preoccipital notch** is an indentation about 5 cm. anterior to the occipital pole.

Fissures and Convolutions. The surface of the cerebrum is not smooth; it is folded into numerous furrows called **fissures** or **sulci,** which throw the surface into irregular folds called **convolutions** or gyri. This arrangement permits of a much greater expanse of gray matter than would be the case with a smooth surface. If detached from the subjacent white matter and fully spread, the gray matter would make an envelope capable of enclosing a much larger structure than the brain. The number and extent of the gyri and the depth of the furrows is to some extent an index to the intellectuality of the individual, which appears to depend upon the amount of gray cortical matter in relation to the bulk of the white matter.

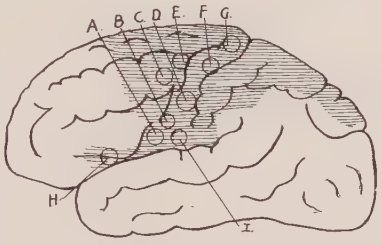

Fig. 27.
Central Fissure and Motor Area of Cortex.
A, Tongue; B, Larynx; C, Head and Eyes; D, Facial Muscles; E, Trunk; F, Upper Extremity; G, Lower Extremity; H, Motor Speech Center; I, Mastication.

The brain fissures are classified as complete or incomplete according as they are or are not due to infoldings of the entire brain wall and produce corresponding elevations within the **lateral ventricles,** which are the cavities hollowed within the hemispheres. The complete fissures, which appear early in foetal life, are few; they are the hippocampal fissure and parts of the calcarine and collateral fissures. The incomplete fissures are numerous and merely dip into the white substance without producing any corresponding elevations in the walls of the ventricular cavity. Those fissures which are considered as dividing the surface of the hemisphere into lobes are called **interlobar;** these are, the lateral cerebral, parietooccipital, calcarine and collateral fissures, the central and cingulate sulci, and the sulcus circularis.

The **Lateral Cerebral Fissure** (*fissure of Sylvius*) is a deep cleft on the under and lateral surfaces of the hemisphere. It has a short **stem** situated at the base of the brain, beginning at a depression at the lateral angle of the anterior perforated substance and extending outward and forward; this stem embraces the lesser wing of the sphenoid. It divides the orbital surface of the frontal lobe from the anterior portion of the temporal lobe and on the lateral surface of the hemisphere divides into three **rami;** an anterior horizontal, an anterior ascending, and a posterior. The **anterior horizontal ramus** extends forward into the inferior frontal gyrus for about 2.5 cm.; the **anterior ascending ramus** passes upward and

is about equally long. The longest of the three is the **posterior ramus,** which runs backward and slightly upward for about 7 cm. and terminates by bending sharply upward in the parietal lobe.

The **Central Sulcus** (*central fissure*) (*fissure of Rolando*) starts upon the medial surface of the hemisphere in the longitudinal fissure, reaches the lateral surface a little behind a point midway between the anterior and posterior poles, to run waveringly downward and forward and terminate a little above the posterior branch of the lateral fissure and about one inch behind the anterior ascending ramus. The central sulcus makes an angle of about 70° with the median plane. It has a **superior genu** with convexity directed backward and an **inferior genu** with convexity forward.

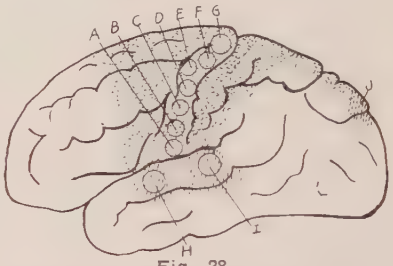

Fig. 28.
Central Fissure and Sensory Area of Cortex.
A, Lower Facial Area; B, Upper Facial Area; C, Fingers; D, Hand; E, Shoulders; F, Elbow; G, Foot; H, Auditory; I, Sensory Speech Center; J, Visual Center.

The **Parietooccipital fissure** is mostly on the medial surface but has a small part on the lateral surface. The medial part starts at a point about 5 cm. in front of the occipital pole and runs downward and forward as a deep cleft on the medial surface. It joins the calcarine fissure below and posterior to the end of the corpus callosum. Often a gyrus is submerged in its depths. This fissure is continued for about a half inch on the lateral surface of the hemispheres.

The **Calcarine** fissure begins in two converging branches near the occipital pole and extends forward to its junction at an acute angle with the parietooccipital fissure just underneath the splenium of the corpus callosum. It is entirely confined to the medial surface. The anterior end of the calcarine fissure corresponds with the bulge in the wall of the lateral ventricle known as the calcar avis.

The **Cingulate Sulcus** (*callosomarginal fissure*), on the medial surface, begins below the ventral extremity of the corpus callosum, runs upward and forward nearly parallel to the rostrum, and, curving in front of the genu, extends backward above the corpus callosum and finally rises to the superior border of the medial surface just behind the central sulcus. It separates the superior frontal and cingulate gyri.

The **Collateral Fissure** reaches from a point near the occipital pole to within a short distance of the temporal pole, entirely on the

tentorial surface. Posteriorly, it lies below and lateral to the calcarine fissure; with the lingual gyrus between; anteriorly it lies between the gyrus hippocampus and the anterior part of the fusiform gyrus.

The **Sulcus Circularis** (*circuminsular fissure*) lies on the lower and lateral surfaces of the hemisphere and circumscribes the insula (*Island of Reil*) so as to divide it from the frontal, parietal, and temporal lobes.

Lobes of the Cerebrum. The division of the cerebral surface into lobes is somewhat arbitrary, being accomplished by the use of certain of the major fissures and sulci and by the addition to these of some imaginary lines to complete boundaries which are naturally incomplete. The lobes are: **frontal, parietal, temporal, occipital, limbic,** and the **insula.**

The Frontal Lobe

The **Frontal Lobe** occupies the anterior part of the hemisphere and is separated from the parietal lobe by the central sulcus. Below it is limited by the posterior ramus of the lateral fissure which lies between it and the central lobe. On the medial aspect the cingulate sulcus separates it from the cingulate gyrus; on the inferior surface the stem of the lateral fissure marks its posterior boundary.

The **lateral surface** of the frontal lobe is divided into four gyri by three sulci; the gyri are the anterior central, and the superior, middle, and inferior frontal. The **precentral sulcus** runs parallel to the central sulcus with the anterior central gyrus between; it is usually divided into an upper and a lower part. From the precentral sulcus the superior and inferior frontal sulci run forward and downward so as to separate three parallel gyri, the superior, middle, and inferior frontal gyri.

The **anterior central gyrus** is bounded behind by the central sulcus and in front by the precentral sulcus; it extends from the supero-medial border of the hemisphere as low as the posterior ramus of the lateral fissure.

The **superior frontal gyrus** is bounded below by the superior frontal sulcus and extends upon the medial surface of the hemisphere. That part on the lateral aspect is partly subdivided by an antero-posterior furrow, the **paramedial sulcus,** into upper and lower divisions.

The **middle frontal gyrus** (*medifrontal gyre*) is the area between the superior and inferior frontal sulci; it is continuous with the anterior orbital gyrus on the inferior surface of the frontal lobe. Sometimes it is subdivided by the **medial frontal sulcus** of Eberstaller, which terminates in a wide bifurcation.

The **inferior frontal gyrus** (*subfrontal gyre*) extends forward from the lower part of the precentral sulcus below the inferior frontal sulcus; it is continuous with the lateral and posterior orbital gyri on the under surface of the hemisphere. The anterior horizontal and ascending rami of the lateral fissure divide it into three parts; the **orbital part,** below the anterior horizontal ramus; the **triangular part,** between the ascending and horizontal rami; and the **basilar part,** behind the anterior ascending ramus. The left inferior frontal gyrus is called the **gyrus of Broca** (*Broca's area*) and, as a rule, is more developed than the right. It is the center for articulate speech.

The **inferior** or **orbital surface** of the frontal lobe, concave in shape, rests upon the orbital plate of the frontal bone. The **orbital** sulcus, shaped much like a letter H, separates it into four gyri named, from their situation, the **medial, lateral, anterior,** and **posterior orbital gyri.** The **olfactory sulcus** traverses the medial gyrus in an antero-posterior direction and the portion medial to this sulcus is termed the **straight gyrus** and is continuous with the superior frontal gyrus on the medial surface.

On the **medial surface** of the frontal lobe lies the medial portion of the superior frontal gyrus, between the cingulate sulcus and the superomedial margin of the hemisphere. In some instances a vertical sulcus marks off the posterior part of this gyrus as the **paracentral lobule,** continuous with the anterior and posterior central gyri.

The Parietal Lobe.

The parietal lobe is quite definitely separated from the frontal lobe by the central sulcus but its separation from the occipital and temporal lobes requires the use of some of those imaginary lines previously referred to. The parietooccipital fissure is the posterior boundary of the parietal lobe as far as it goes and this boundary is continued by an imaginary line from the end of that fissure to the preoccipital notch. The posterior ramus of the lateral fissure separates the parietal from the temporal lobe and beyond its termi-

nation an imaginary line curves backward to meet the line passing downward from the preoccipital notch. In fact, the parietal, occipital, and temporal lobes have a common area of meeting unmarked by any natural delimitation.

The **lateral surface** of the parietal lobe presents but one well-marked sulcus, the **intraparietal sulcus,** which, however, is composed of two parts, an oblique and a horizontal. The former is called the **postcentral sulcus** and marks off the postcentral gyrus. It begins about halfway between the lower end of the central sulcus and the upcurved extremity of the lateral fissure and runs upward and backward, parallel to the central sulcus; it may divide into an upper and lower branch. The **horizontal portion** of the intraparietal sulcus begins about the middle of the postcentral sulcus or from the upper end of its inferior branch and runs backward and slightly upward across the parietal lobe to be prolonged into the occipital lobe under the name **occipital ramus**. In that lobe it separates into two parts forming the **transverse occipital sulcus.** The part of the parietal lobe above the horizontal portion of the intraparietal sulcus is called the **superior parietal lobule;** that which is below, the **inferior parietal lobule.**

The **posterior central gyrus** is bounded in front by the central sulcus and behind by the postcentral sulcus. It extends from the longitudinal fissure above to the posterior ramus of the lateral fissure below. It parallels the anterior central gyrus and is sometimes connected with it below, and less often above, the central sulcus. The postcentral gyrus is the cortical area for reception of impressions of touch from the general periphery.

The **superior parietal lobule** is separated from the inferior parietal lobule below by the horizontal limb of the intraparietal sulcus; in front, it lies behind the upper part of the postcentral sulcus but is often connected with the postcentral gyrus above the end of the sulcus; posterior to it is the lateral portion of the parietooccipital fissure, around the end of which it is joined to the occipital lobe by a curved gyrus, the **arcus parietooccipitalis.**

The **inferior parietal lobule** is bounded in front by the lower part of the postcentral sulcus and above by the horizontal part of the intraparietal. It is made up of two gyri, the **supramarginal,** which arches over the upturned end of the lateral fissure and touches the postcentral gyrus in front and the superior temporal gyrus rearword; and the **angular,** which curves over the posterior end of the superior temporal sulcus and touches the middle temporal gyrus.

The **medial surface** of the parietal lobe is made up of one small square convolution, the **precuneus**, or **quadrate lobe.** It is bounded anteriorly by the posterior end of the cingulate sulcus; behind by the medial part of the parietooccipital fissure; and inferiorly by the subparietal sulcus, which separates it from the cingulate gyrus.

The Occipital Lobe.

This lobe is small and pyramidal in shape and presents for examination three surfaces: **lateral, medial,** and **tentorial.**

The **lateral surface** is bounded anteriorly by the parietooccipital sulcus and by an imaginary line drawn from the end of this sulcus to the preoccipital notch. It is divided by two sulci. The **transverse occipital sulcus** is continuous with the posterior end of the occipital ramus of the intraparietal sulcus and crosses the upper part of the lobe behind the parietooccipital fissure. The **lateral occipital sulcus** extends from behind forward and separates the lateral surface of the lobe into a **superior** and **inferior gyrus,** continuous respectively with the parietal and temporal lobes in front.

The **medial surface** of the occipital lobe is limited anteriorly by the medial part of the parietooccipital fissure and is subdivided into the cuneus and the lingual gyrus by the calcarine fissure. The **cuneus** is a wedge-shaped area between the calcarine fissure and the medial part of the parietooccipital fissure. The **lingual gyrus** is between the calcarine fissure and the posterior part of the collateral fissure; it reaches the occipital pole behind and in front continues on to the tentorial surface of the temporal lobe and unites with the hippocampal gyrus.

The **tentorial surface** of the occipital lobe is made up of the posterior part of the **fusiform gyrus** and the lower part of the lingual gyrus, separated by the posterior part of the collateral fissure. This surface extends forward to an imaginary line drawn through the preoccipital notch.

The Temporal Lobe.

The temporal lobe presents three surfaces: a **superior,** a **lateral,** and an **inferior.**

The **superior surface** is limited above by the lateral fissure and overlaps the insula. Three or four gyri, called **transverse temporal gyri,** arise in the bottom of the posterior end of the lateral fissure;

these run obliquely outward and forward on the upper surface of the superior temporal gyrus.

The **lateral surface** lies below the posterior ramus of the lateral fissure and an imaginary line continued backward from it and above the infero-lateral border of the hemisphere. It is divided by the superior and middle temporal sulci into the superior, middle, and inferior temporal gyri. The **superior temporal sulcus** runs from before backward across the lateral surface, parallel with, but somewhat below, the posterior ramus of the lateral fissure; the **middle temporal sulcus** is below and parallel with the superior. The **superior temporal gyrus,** above the superior temporal sulcus, continues behind into the supramarginal and angular gyri. The **middle temporal gyrus,** between the superior and inferior temporal sulci, joins behind with the angular gyrus. The **inferior temporal gyrus,** below the inferior temporal sulcus, unites behind with the inferior occipital gyrus and extends around the infero-lateral border to the under surface of the hemisphere where it reaches the inferior sulcus.

The **inferior surface** is concave and is continuous behind with the tentorial surface of the occipital lobe. The **inferior temporal sulcus** crosses it from behind forward, from a point near the occipital pole to within a short distance of the temporal pole in front. It is often bridged by crossing gyri. Medial to this fissure is the **fusiform gyrus,** which is limited medially by the collateral fissure which divides it from the lingual gyrus behind and the hippocampal gyrus in front. Lateral to the inferior sulcus is the narrow portion of the inferior temporal gyrus reflected from the lateral surface.

The Insula.

The Insula (*central lobe, Island of Reil*). Hidden within the depths of the lateral fissure and so overhung by the more prominent frontal and temporal lobes that it cannot be seen in the developed brain without drawing apart the lips of the lateral fissure, lies the **insula.** It is circumscribed by the **circular sulcus.** The gyri of adjacent lobes which bound the lateral fissure so as to overlap the insula are called

Fig. 29. The Insula (Island of Reil).

the **opercula of the insula**; they are separated from each other by the three rami of the lateral fissure and are named the orbital, frontal, fronto-parietal, and temporal opercula. The **orbital operculum** lies behind the anterior horizontal ramus of the fissure, the **frontal** between that ramus and the anterior ascending, the **fronto-parietal** between the anterior ascending ramus and the upcurved end of the posterior ramus, and the **temporal** below the posterior ramus.

When the lips of the lateral fissure are drawn back the insula appears as a triangular eminence with its apex directed toward the anterior perforated substance. A deep sulcus runs backward and upward from the apex to divide the insula into a larger anterior and a smaller posterior part. The anterior part presents three or four short gyri divided by shallow sulci; the posterior part is one long gyrus. Deeply, the insula reaches the lentiform nucleus of the corpus striatum. The insular cortex is continuous with that of the surrounding opercula.

Connections of the Olfactory Nerves.

The olfactory nerves arise in groups of ganglionic cells in the upper third of the mucous membrane lining the nasal cavity, are collected into nineteen or twenty strands on each side, ascend through the lamina cribosa of the ethmoid bone and enter the under surface of the **olfactory bulb.** Their connections thereafter were formerly believed to belong entirely to a more or less separately developed part of the cerebrum, the rhinencephalon. which in some lower animals is so largely developed as to dwarf the neopallium but which in man is comparatively subordinate. It is now conceded, however, that certain structures related to the olfactory pathway belong by development to the neopallium. To these structures, including the cingulate and hippocampal gyri, which arch around the corpus callosum and the hippocampal fissure, the term **limbic lobe** has been given by Broca. To the remaining brain structures related to the olfactory pathway the name **rhinencephalon** is given.

The **cingulate gyrus** (*callosal convolution*) is separated by the **callosal fissure** from the corpus callosum, which it parallels. It begins below the rostrum, curves in front of the genu, and extends backward to descend behind the splenium, where it connects with the hippocampal gyrus by a narrow isthmus. The cingulate sulcus separates it from the medial part of the superior frontal gyrus and the subparietal sulcus from the precuneus.

The **hippocampal gyrus** lies below the hippocampal fissure and above the anterior part of the collateral fissure. It is connected behind with the cingulate gyrus by the isthmus and below with the lingual gyrus. The anterior end of the hippocampal gyrus is a hook (*uncus*), separated from the apex of the temporal lobe by a slight groove, the **incisura temporalis.**

The **hippocampal fissure** (*dentate fissure*) is a complete fissure which causes a bulge, the hippocampal eminence, in the inferior cornu of the lateral ventricle. It begins just behind the splenium of the corpus callosum and runs forward between the hippocampal and dentate gyri to end in the uncus.

The Rhinencephalon.

The rhinencephalon embraces the following parts, all related to the function of smell: the **olfactory lobe,** the **uncus,** the **subcallosal** and **supracallosal gyri,** the **fascia dentata hippocampi,** the **septum pellucidum,** the **fornix,** and the **hippocampus.**

The **Olfactory Lobe** lies beneath the orbital surface of the frontal lobe near the mid-line. In man it is by no means so well developed as in many lower vertebrates. Its parts are: the **olfactory bulb,** the **olfactory tract,** the **olfactory trigone,** the **parolfactory area of Broca,** and the **anterior perforated substance.**

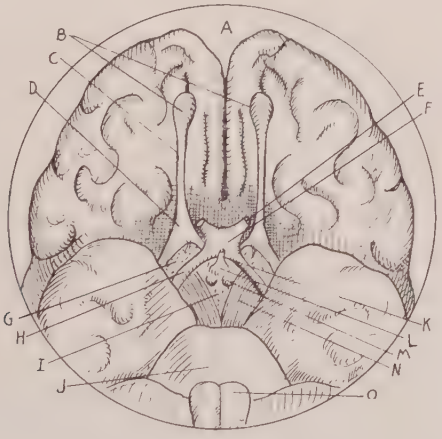

Fig. 30. Olfactory Bulb and Tract.
A, Longitudinal Fissure; B, Olfactory Bulb; C, Olfactory Nerve; D, Olfactory Trigone; E, Optic Nerve; F, Optic Chiasma; G, Anterior Perforated Substance; H, Optic Tract; I, Posterior Perforated Substance; J, Pons; K, Infundibulum; L, Tuber Cinereum; M, Mammillary Bodies; N, Cerebral Peduncles; O, Medulla Oblongata.

(a) The **olfactory bulb** is an oval reddish-gray mass which rests upon the cribriform plate of the ethmoid. The fibres of the

olfactory nerve, which have arisen in the ganglion cells of the Schneiderian membrane, and penetrated the lamina crivrosa, enter its under surface. In some animals the bulb contains a cavity but in man this is not present, neuroglia filling the space. The dorsal wall of the bulb is scantily developed but the ventral is thickened and important. Section through the ventral part reveals four layers from without inward; (1) a layer of olfactory nerve fibres (*non-medullated*). These enter the bulb, at first covering it and then penetrating to its interior where they terminate by forming synapses with the dendrites of the mitral cells. (2) a glomerular layer, containing numerous rounded enlargements, the **glomeruli**, caused by the arborization of process of the olfactory nerve fibres with the descending dendrites of the mitral cells. (3) a molecular layer composed of neuroglia in which are embedded the mitral cells. Each mitral cell gives off a thick dendrite which descends into the glomerular layer and arborizes. (4) the nerve fibre layer which contains the axons of the mitral cells, which in this layer turn at right angles and pass on their way to the brain. This layer may contain some efferent fibres, but nothing certain is known about them.

(b) The **olfactory tract** lies in the olfactory sulcus on the under surface of the frontal lobe; it is a narrow white band, triangular in coronal section with its apex upward, which divides posteriorly into two striae, a medial and a lateral. The **lateral stria** crosses the lateral part of the anterior perforated substance and then turns medialward toward the uncus of the hippocampal gyrus. The **medial stria turns** medialward behind the parolfactory area and terminates in the subcallosal gyrus; sometimes a small **intermediate stria** runs backward in the anterior perforated substance.

(c) The **olfactory trigone** is a small triangular area in front of the anterior perforated substance. Its anteriorly directed apex occupies the posterior part of the olfactory sulcus.

(d) The **parolfactory area of Broca** is a small triangular area on the medial surface of the hemisphere in front of the subcallosal gyrus; it is continuous below with the olfactory trigone and above and in front with the cingulate gyrus. It is limited before and behind by the anterior and posterior parolfactory sulci.

(e) The **anterior perforated substance** lies in front of the optic tract and behind the olfactory trigone; it is roughly quadrilateral in shape. Medially and in front it joins the subcallosal gyrus; lat-

erally it is limited by the olfactory striae and is continued into the uncus. Its gray substance is continuous above with that of the corpus callosum. The name of this substance is derived from the fact of its numerous perforations for blood vessels.

The **Subcallosal, Supracallosal,** and **Dentate Gyri** form an arched gray lamina over the corpus callosum and above the hippocampal gyrus from the anterior perforated substance to the uncus.

(a) The **subcallosal gyrus** (*peduncle of the corpus callosum*) is a narrow strip on the medial surface of the hemisphere in front of the lamina terminalis, behind the parolfactory area, and below the rostrum of the corpus callosum. It joins the supracallossal gyrus adjacent to the genu of the corpus callosum.

(b) The **supracallosal gyrus** (*gyrus epicallosus*) is a thin layer of gray matter in contact with the upper surface of the corpus callosum and continuous with the cingulate gyrus laterally. It contains two strands of white matter known as the **medial** and **lateral longitudinal striae.**

(c) The **fascia dentata hippocampi** (*gyrus dentatus*) is a narrow band separated from the hippocampal gyrus by the hippocampal fissure. In front, it continues to the notch of the uncus where it bends and is prolonged over the surface of the uncus in which it disappears.

The remaining parts of the rhinencephalon, which are the septum pellucidum, fornix, and hippocampus, will be described with the lateral ventricle.

STRUCTURE OF THE CEREBRAL HEMISPHERES

Each cerebral hemisphere encloses an irregular cavity, the **lateral ventricle.** Each is surfaced, except at its union in the median line with the opposite hemisphere, by a layer of gray substance, the **cortex.** Between the ventricle and the cortex are interposed certain gray masses, or mixed gray and white masses, and surrounding these, and occupying the remainder of the hemisphere, is a considerable mass of white matter. The white matter consists of three sets of fibres; (a) **projection fibres,** which serve to connect the cerebral cortex with the basal ganglia or with more remote parts of the central nerve system; (b) **association** (*arcuate*) **fibres,** which are confined each to its own hemisphere and link together different cortical areas; and (c) **commissural fibres,** which cross

the midline from one hemisphere to the other to bring similar or related areas of the two sides into communication with each other. The major portion of these transverse fibres are gathered to form the **corpus callosum.**

If a transverse section be made through the hemispheres about 1.25 mm. above the corpus callosum, each hemisphere will appear on its cut surface as an oval-shaped area, studded with tiny red spots (*puncta vasculosa*) where blood-vessels have been cut, and edged by a convoluted gray border, the cortex. Drawing apart the medial margins of the hemispheres, the bottom of the longitudinal fissure will disclose a white mass, the corpus callosum. If a second transverse section be made at the level of the corpus callosum the latter will be seen as a broad, arched band, extending for some distance into the substance of each hemisphere. The overlapping margins of the hemispheres above the corpus callosum are called **labia cerebri**; each labium is part of the cingulate gyrus and is separated from the corpus callosum by the callosal fissure.

The **Corpus Callosum** is a broad, arched band of white fibres, connecting the two hemispheres across the midline and roofing in the lateral ventricles. It is the great transverse commissure of the brain. In a median sagittal section of the brain, the corpus callosum is about 10 cm. in length and forms an arch. It lies nearer the anterior than the posterior pole, reaching to within 4 cm. of the former and about 6 cm. of the latter.

The **anterior end**, called the **genu**, is curved downward and backward in front of the septum pellucidum, then becomes thinner and extends backward as the **rostrum**, which connects below with the lamina terminalis. In contact with the under surface of the rostrum are the anterior cerebral arteries, which then arch over the front of the genu and turn backward over the body of the corpus callosum.

The **posterior end**, or **splenium**, is the thickest part of the corpus callosum. It overhangs the tela choroidea of the third ventricle and the mid-brain, and presents a thick, convex, free border posteriorly. The posterior edge is acutely bent under, so that the upper and lower parts are applied to each other.

The **superior surface** is about 2.5 cm. in width and is convex from before backward. Its middle lies at the bottom of the longitudinal fissure and is in contact posteriorly with the lower edge of

the falx cerebri. Laterally, it is overhung by the labia cerebri and separated from them by the callosal fissures. It is surfaced above by a thin layer of gray matter, the **supracallosal gyrus,** which has numerous transverse grooves and also shows the medial and lateral longitudinal striae already described. (page 84).

The **inferior surface** is concave and forms the roof of the lateral ventricle on either side. This surface is attached in front to the septum pellucidum and behind this to the upper surface of the body of the fornix; the splenium is in contact below with the tela choroidea.

The fibres which compose the corpus callosum are divided on either side into three groups as they radiate into the substance of the hemisphere. These groups are (a) the **forceps anterior,** curving forward from the genu into the frontal lobe; (b) the **forceps posterior,** curving backward into the occipital lobe; and (c) the **tapetum,** which is the principal group of fibres and extends laterally across the roof of the lateral ventricle and into the temporal lobe.

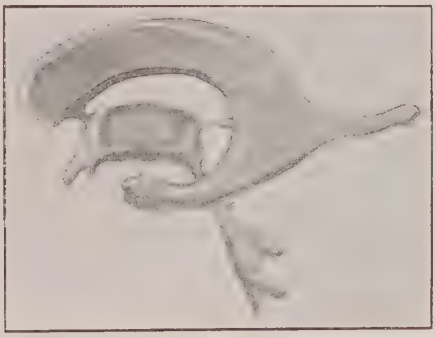

Fig. 31. Outline of Lateral Ventricle.

The **Lateral Ventricles.** The two lateral ventricles are the hollow cavities, one in each hemisphere, in the lower and medial part. A vertical partition in the mid-line, the **septum pellucidum,** separates them but an **interventricular foramen** opens from each lateral ventricle into the third ventricle and thus indirectly they communicate with each other. Each lateral ventricle is filled with cerebrospinal fluid and is lined by a delicate membrane, the **ependyma,** surfaced by ciliated epithelium. The cavities are of an irregular and peculiar shape, sometimes likened to that of an anvil with three curved horns. Each may be described as having a **body,** or **central part,** and three **cornua.**

The **central part** of the lateral ventricle extends from the interventricular foramen back as far as the splenium of the corpus callosum. It is irregularly curved, triangular on transverse section, and has a roof, a floor, and a medial wall. The roof is formed by the under surface of the corpus callosum; the floor, from before backward, by the caudate nucleus of the corpus striatum, the striae terminalis and the terminal vein, the lateral part of the upper surface of the optic thalamus, the choroid plexus, and the fornix; the medial wall is the posterior part of the septum pellucidum. Opening from the central part of each lateral ventricle are three curved prolongations of the cavity, known as the **anterior, posterior,** and **inferior cornua.**

The **anterior cornu** extends forward, lateralward, and slightly downward from the interventricular foramen into the substance of the frontal lobe, curving around the anterior end of the caudate nucleus. Its floor is the upper surface of the rostrum of the corpus callosum. Medially, it is limited by the anterior end of the septum pellucidum and laterally by the head of the caudate nucleus. Its apex reaches the posterior surface of the genu of the corpus callosum.

The **posterior cornu** reaches at first backward and lateralward, and then medialward into the occipital lobe. It is roofed in by those fibres of the corpus callosum passing to the temporal and occipital lobes. Its medial wall presents a longitudinal bulge, the **calcar avis,** (*hippocampus minor*) produced by the calcarine fissure. Another projection, the **bulb of the posterior cornu,** is caused by the forceps posterior of the corpus callosum.

The **inferior cornu,** (*middle horn*) is the largest of the three. It forms a curve around the posterior end of the thalamus and then penetrates to within 2.5 cm. of the apex of the temporal lobe. From its origin its direction is at first backward, lateralward, and downward; it then turns forward along a line represented by the superior temporal sulcus, to its termination. It is roofed in principally by the tapetum of the corpus callosum, but the tail of the caudate nucleus and the striae terminalis also extend in the roof to its extremity, where the tail of the caudate nucleus joins the putamen. Its floor presents the hippocampus, the fimbria hippocampi, the collateral eminence, and the choroid plexus.

The **hippocampus** is a curved eminence caused by the infolding of the wall of the hemisphere along the line of the hippocampal

fissure, and extending throughout the entire length of the inferior cornu, a distance of about 5 cm. Its lower end is enlarged and spreads into digitations which give it a paw-like appearance, hence its name, **pes hippocampi.** Most of the hippocampus is gray matter but a thin white layer, the **alveus,** lies on the ventricular surface and is continuous with the fimbria hippocampi.

The **collateral eminence** lies parallel with the hippocampus and lateral to it as an elongated swelling marking the involution of the wall along the middle of the collateral fissure.

The fimbria hippocampi is a continuation of the crus of the fornix.

The **Corpus Striatum** is so named because of its striped appearance, due to alternate laminations of gray and white matter in its anterior portion; the greater part of its bulk is gray substance. The corpus striatum lies lateral to the optic thalamus and nearer the base than the vertex of the hemisphere. It is partly within the lateral ventricle, the **intraventricular portion,** or **caudate nucleus,** and partly without the ventricle, the **extraventricular portion,** or **lentiform nucleus.** The latter is embedded in the white matter of the hemisphere.

The **caudate nucleus** is a mass of gray matter in the form of a pear, with an elongated, highly-arched tail. Its **head,** or broad, blunt extremity, extends forward into the anterior cornu of the lateral ventricle and is attached to the anterior perforated substance and the anterior end of the lentiform nucleus; its **tail,** or narrow, elongated extremity, extends backward along the lateral surface of the thalamus, with the stria terminalis and terminal vein between them; it then descends into the roof of the inferior cornu of the lateral ventricle and continues outward with the cornu to end in the putamen near the apex of the temporal lobe. The anterior part of the caudate nucleus unites with the lentiform nucleus but throughout most of the extent of the former it is separated from the latter by a thick lamina of white matter called the **internal capsule.**

The **lentiform nucleus** (*O.T. lenticular nucleus, lenticula*) lies lateral to the caudate nucleus and thalamus. On coronal section it is somewhat triangular in shape and in horizontal section it has the appearance of a biconvex lens. It is shorter than the caudate nucleus and does not reach so far forward but unites with the caudate nucleus at its anterior end. It is limited laterally by a

layer of white matter called the **external capsule,** lateral to which lies a thin plate of gray matter, the **claustrum.**

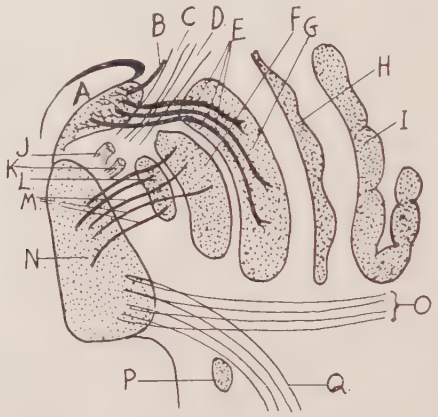

Fig. 32. Schema Showing Relation of Thalamus, Lentiform, Caudate, and Other Nuclei, and Fibre Tracts.
A, Lateral Ventricle; B, Cortico-Striate Tracts; C, Fronto-pontine Tract; D, Anterior Thalamic Radiations; E, Lenticulo-Caudate Fibres; F, Anterior Part of Globus Pallidus; G, Putamen; H, Claustrum; I, Insula; J, To Oculomotor Nucleus; K, To Facial, Vagal, Trigeminal, and Hypoglossal Nuclei; L, Medial Part of Globus Pallidus; M, Ansa Lenticularis; N, Thalamus; O, Auditory Radiations; P, Tail of Caudate Nucleus; Q, Optic Radiations.

The lentiform nucleus is seen in coronal section to be divided into three parts by two **medullary laminae;** the lateral and larger part is a reddish mass called the **putamen;** the medial and intermediate are yellowish and are called the **globus pallidus.**

The corpus striatum is largely ganglionic; it contains a multitude of gray cells; it is, however, traversed by numerous strands of white fibres, some of which originate in its large, multipolar cells, and many of which originate externally. The principal fibre groups in the corpus striatum are: (a) **corticostriate fibres,** arising in the corpus striatum and passing to the cerebral cortex; (b) **striato-thalamic** and **thalamo-striate** fibres, which pass through the internal capsule or through a strand named the **ansa lentiformis;** (c) fibres which leave the under side of the caudate and lentiform nuclei and pass to the cerebral peduncle; and (d) **striato-striate** fibres, which pass in both direction between the caudate and lentiform nuclei.

The **Claustrum** is a layer of gray matter just lateral to the external capsule. Its medial surface is smooth but its lateral surface is ridged and furrowed to correspond with the gyri of the insula to which it is closely related. The claustrum is believed to be a detached portion of the insula, from which it is separated only

by a thin layer of white fibres, the **capsula extrema**, or band of Baillarger. Its cells are like those of the deeper layer of the cortex, being small, spindle-shaped, and yellow-pigmented.

The **Amygdala** (*nucleus amygdalae*) is an ovoid mass of gray matter at the lower end of the roof of the inferior cornu; it is a localized thickening of the gray cortex, continuous with the uncus; in front, it touches the putamen; behind, the tail of the caudate nucleus and the stria terminalis. It is sometimes classified with the optic thalamus, and the corpus striatum as one of the **basal ganglia.**

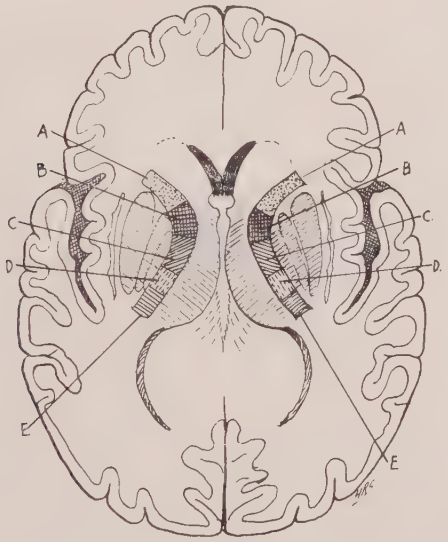

Fig. 33. Transverse Section of Cerebrum (Schema), Showing Internal Capsule.
A, Frontopontine Tract; B, Genicular Fibres; C, Cerebrospinal Tract; D, Spino-Encephalic Tract; E, Optic Radiations.

The **Internal Capsule** is a flattened band of white fibres interposed between the lentiform nucleus laterally and the caudate nucleus and optic thalamus medially. On transverse section of the brain it presents a curved outline with the convexity medialward. The prominence of the curve is almost an angle and is called the **genu.** That part in front of the genu is called the frontal part, or anterior limb; it lies between the lentiform and caudate nuclei. The part behind the genu is the occipital part, or posterior limb, and separates the lentiform nucleus from the thalamus.

The internal capsule is an extremely important part of the white matter of the brain because here are compacted many important tracts which elsewhere in their course spread out over a

wider area, and because of its juxtaposition to the **lenticulo-striate arteries,** which are peculiarly liable to rupture, embolism, or thrombosis. Through the **frontal** portion of the internal capsule pass the following groups of fibres: (1) **thalamo-frontal fibres,** from the optic thalamus to the cortex of the frontal lobe; (2) **striato-striate** fibres, uniting the caudate and lentiform nuclei; (3) **cortico-striate** fibres, linking the cortex with the corpus striatum; and (4) **fronto-pontine** fibres, which pass from the frontal cortex, through the medial one-fifth of the base of the cerebral peduncle, to the nuclei pontis. In the region of the **genu** the fibres are termed **geniculate** fibres; they originate in the motor (*precentral*) area of the cerebral cortex and after passing through the genu descend through the middle portion of the base of the cerebral peduncle with the cerebrospinal fibres, decussate, and terminate in relation with the motor nuclei of the cranial nerves of the opposite side; they constitute the cortico-nuclear pathway of control for the voluntary muscles of the head and face. The anterior two-thirds of the **occipital** portion of the internal capsule conveys the cerebrospinal fibres which, like those just described, arise in the motor area of the cortex, traverse the capsule, descend in the middle three-fifths of the base of the cerebral peduncle, decussate either in the medulla or the cord, and finally terminate in relation to the motor spinal nerve nuclei on the opposite side. These, with the geniculate fibres, really constitute one great tract, the **direct motor tract,** which brings the cortex into control of voluntary muscles. In the capsule, the fibres destined for the head and face are most anterior; those for the leg and foot most posterior. The posterior third of the occipital portion (*posterior limb, retrolenticular limb*) contains the following fibre groups: (1) **sensory fibres,** some of which are thalamo-cortical, while some are continued upward from the medial lemniscus to the sensory (*postcentral*) area of the cortex; (2) the **optic radiations,** made up of fibres arising in the lower visual centres (*pulvinar, lateral geniculate body, superior colliculus*) and passing to the cortex of the occipital lobe; (3) **acoustic** fibres, passing from the lateral lemniscus to the cortex of the temporal lobe as **auditory radiations;** and (4) **occipito-pontine** and **temporo-pontine** fibres, from the cortex of these lobes, through the posterior end of the retrolenticular limb of the internal capsule, and through the lateral one-fifth of the crusta of the cerebral peduncle to the nuclei pontis.

These various fibre groups, described above as traversing the internal capsule, spread out on the cortical side of the capsule into a series of divergent strands called the **corona radiata** and on their

way to the cortex intermingle with the fibres of the corpus callosum and with the arcuate, or association, fibres which pass between the different lobes and gyri of the cerebral surface.

The **External Capsule** is a thin layer of white substance interposed between the claustrum laterally and the lentiform nucleus medially. It probably gets its fibres from the thalamus, the subthalamic region, and the anterior commissure.

The **Substantia Innominata of Meynert** is a layer of gray and white substance beneath the lentiform nucleus and the anterior part of the thalamus. Its upper layer is termed the **ansa lentiformis** and contains fibres from the lens to the thalamus. The middle layer contains both cells and fibres; fibres enter into it from the parietal lobe through the external capsule; others unite it with the medial longitudinal bundle. The inferior connects the thalamus with the temporal lobe and insula.

The **Stria Terminalis** is a narrow band of white matter between the caudate nucleus and the thalamus. Anteriorly, its fibres partly continue into the column of the fornix but some enter the anterior commissure; posteriorly, it runs into the roof of the inferior cornu of the lateral ventricle and at its extremity connects with the amygdala.

The **Fornix** is an arched plate of white matter extending longitudinally beneath the corpus callosum, separated from it in front by the septum pellucidum but connected with it behind. The parts of the fornix belonging to the two hemispheres are connected with each other in their central parts at the midline but are separated front and back. The separated front portions are called the **columns of the fornix,** the central united part the **body**, and the posterior parts, the **crura.**

The **body** of the fornix is triangular, narrow in front and wider behind. Its upper surface connects with the septum pellucidum and corpus callosum and the lateral part of it helps to form the floor of the lateral ventricle. Its under surface rests upon the tela choroidea of the third ventricle.

The **columns** of the fornix curve downward in front of the interventricular foramen and behind the anterior commissure and each descends through the gray substance in the lateral wall of the third ventricle to end in the corpus mammillare. The corpus mammillare gives origin to the **thalamomammillary fasciculus** (*bundle of Vicq d'Azyr*) which passes to the anterior nucleus of the thala-

mus. This fasciculus together with the column of the fornix, completes a figure much like an 8, but interrupted at the corpus mammillare. The column of the fornix receives the stria medullaris of the pineal body, some fibres of the stria terminalis, and some from the septum pellucidum.

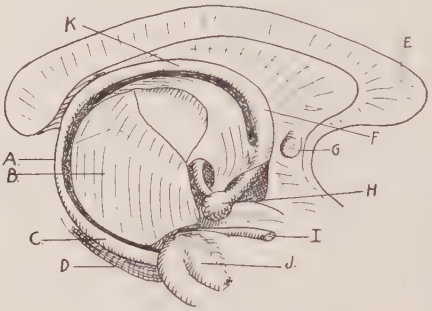

Fig. 34. Relations of the Fornix.
A, Crus Fornicis; B, Thalamus; C, Fimbria Hippocampi; D, Fascia Dentata Hippocampi; E, Genu of Corpus Callosum; F, Columns of Fornix; G, Anterior Commissure; H, Mammillary Body; I, Optic Nerve; J, Uncus; K, Corpus Fornicis.

The **crura** of the fornix are flattened, divergent bands, extending backward from the body. At first each is closely connected with the corpus callosum; it then curves outward around the posterior end of the thalamus and slants obliquely downward and forward into the inferior cornu of the lateral ventricle, where it lies along the concavity of the hippocampus. On the hippocampus some of its fibres spread out to form the **alveus** while others are continued as the **fimbria hippocampi** into the uncus. The medial margin of the fimbria overlaps the **fascia dentata hippocampi.**

Interventricular Foramen (*foramen of Monro*). The interventricular foramen is an oval aperture of communication between the third ventricle and the lateral ventricle. There is one on either side, between the columns of the fornix and the anterior ends of the thalami. Behind the epithelial lining of the foramen the choroid plexuses of the lateral ventricles are joined across the median line.

The **Anterior Commissure** (*precommissure*) is a transverse mass of white fibres connecting the temporal lobes across the midline but also containing some decussating fibres from the olfactory tract. It lies in front of the columns of the fornix and on sagittal section is seen to be oval in shape with its greatest (*vertical*) dimension measuring about 5 mm.

The **Septum Pellucidum** (*septum lucidum*) is a double lamina, vertically placed between the bodies and anterior cornua of the lateral ventricles, beneath the corpus callosum. Its laminae are partly separated by a slot, the **cavity of the septum pellucidum.** This cavity, sometimes called the fifth ventricle, is believed to be a part of the longitudinal cerebral fissure blocked off by the union of the two sides of the corpus callosum above and the fornix below. Each half of the septum walling in the cavity forms part of the medial wall of the hemisphere and has a medial gray layer, similar to the cortex, and a lateral white layer. The cavity never communicates with the ventricles of the brain and is not developed from the cavity of the embryonic cerebral vesicles.

The **Choroid Plexus of the Lateral Ventricle** is a fringed process of pia mater projecting into the ventricular cavity. It is highly vascular and is covered by a layer of epithelium reflected from the lining of the ventricle. At the interventricular foramen each choroid plexus unites with its fellow of the opposite ventricle and from here it extends as far as the tip of the inferior cornu. That part belonging to the body of the ventricle forms the vascular fringed margin of the **tela choroidea of the third ventricle.** The arteries which feed the choroid plexus are (a) the anterior choroidal, a branch of the internal carotid, and (b) the posterior choroidal, a branch of the posterior cerebral. The veins of the choroid plexus unite to form a tortuous vein which at the interventricular foramen unites with the terminal vein to form the internal cerebral vein.

The **Tela Choroidea of the Third Ventricle** (*velum interpositum*) is a double, triangular fold of pia mater beneath the fornix. The medial portion of its lower surface is in contact with the epithelial roof of the third ventricle while the lateral portion rests upon the thalamus. Its apex corresponds with the interventricular foramen and its base with the splenium of the corpus callosum. Its lateral margins are modified to form the choroid plexuses of the lateral ventricles. The arteries which supply this plexus are the anterior and posterior cerebral; the veins which drain it are the internal cerebral veins which unite to form a single trunk, the great cerebral vein (*vena magna Galeni*) which ends in the straight sinus.

STRUCTURE OF THE CEREBRAL HEMISPHERES

The cerebral hemisphere is made up of an external layer of gray matter, called the **cortex,** a mass of white matter surrounded

by the cortex and making up the bulk of the hemisphere, and certain mixed gray and white structures embedded in the depths of the white mass and known collectively as the **basal ganglia**; these are the caudate nucleus, the lentiform nucleus, the claustrum, and the amygdala.

The **white substance** is composed of medullated nerve fibres, of various sizes, and bound together by neuroglia into bundles of varying compactness. These fibres are best classified by their course and connections, in three groups or systems. (1) **Projection fibres** unite the cortex with the lower parts of the brain stem; they carry impulses from the cortex to these lower centers and bring impressions from the lower centers to the cortex. (2) **Commissural,** or transverse fibres unite the two hemispheres. (3) **Association** fibres connect different organs within the same hemisphere; they may be collaterals of the projection fibres but many have separate cells of origin.

1. The **projection fibres** are both efferent and afferent. The principal efferent groups are (1) the motor tract, which is gathered into the genu and anterior two-thirds of the posterior limb of the internal capsule and consists of (a) the **geniculate fibres,** which decussate and end in the motor cranial nerve nuclei of the opposite side and (b) the **cerebrospinal fibres,** which occupy the anterior two-thirds of the occipital limb of the internal capsule and then descend through mid-brain, pons, and the pyramid of the medulla to decussate and terminate in relation to the nuclei of origin of the motor spinal nerves of the opposite side; (2) the **corticopontine fibres** which pass partly through the anterior and partly through the posterior limb of the internal capsule and end in the nuclei pontis. These corticopontine fibres include frontopontine, temporopontine, and occipitopontine strands, and are the beginning of the **indirect motor pathway.**

The chief afferent fibre groups are: (1) those of the lemniscus which do not terminate in the thalamus; (2) those of the superior cerebellar peduncles which are not interrupted in the red nucleus or the thalamus; (3) thalamocortical fibres, in great numbers, arising in the thalamus and radiating in all directions to various cortical areas; (4) fibres of the optic and acoustic pathways, arising in the lower visual and auditory centers, passing through the posterior end of the occipital limb of the internal capsule and passing respectively to the cortex of the occipital and temporal lobes.

These groups of projection fibres, both efferent and afferent, gathered at the base of the brain medially into a comparatively compact area, spread out more widely as they approach the cortex and to this spreading the name **corona radiata** is given.

The **commissural** or transverse fibres connect the two hemispheres across the midline. They are arranged in four groups already described, three principal, the corpus callosum, the anterior commissure, and the posterior commissure, and one lesser, the **lyra,** or hippocampal commissure.

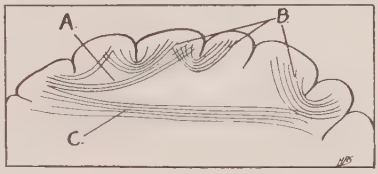

Fig. 35. Schema showing Association Fibres of Cerebrum.
A, Intermediate fibres; B, Short (intergyral) association fibres; C, Long (interlobar) association fibres.

The **association** fibres are those which link together different areas of the same hemisphere. They are **short association fibres,** which connect adjacent gyri, and **long association fibres,** which unite gyri more widely separated. The short fibres lie close to the surface and are intermingled with the projection fibres in such a way as to increase the bulk of the corona radiata near the cortex.

The long association fibres include certain well-defined groups, as follows: (a) the uncinate fasciculus; (b) the cingulum; (c) the superior longitudinal fasciculus; (d) the inferior longitudinal fasciculus; (e) the perpendicular fasciculus; (f) the occipitofrontal fasciculus; and (g) the fornix.

(a) The uncinate fasciculus crosses the bottom of the lateral fissure to connect the anterior end of the temporal lobe with the gyri of the frontal lobe.

(b) The cingulum is a curving band of white matter within the cingulate gyrus. It begins in front of the anterior perforated substance, passes forward and upward parallel to the rostrum, curves with the genu, follows the corpus callosum backward to its splenium, around which it curves, and ends in the gyrus hippocampus.

(c) The superior longitudinal fasciculus extends backward from the frontal lobe superior to the lentiform nucleus and the insula; some of its fibres end in the occipital lobe while others curve downward and end in the temporal lobe.

(d) The inferior longitudinal fasciculus follows the lateral walls of the posterior and inferior cornua of the lateral ventricle and serves to connect the occipital and temporal lobes.

(e) The perpendicular fasciculus connects the inferior parietal lobule with the fusiform gyrus and runs vertically through the anterior part of the occipital lobe.

(f) The occipitofrontal fasciculus extends from the frontal lobe backward past the lateral edge of the caudate nucleus; its fibres spread out fanwise into the occipital and temporal lobes.

(g) The fornix connects the hippocampal gyrus with the corpus mammillare and, through the thalamomammillary fasciculus, with the thalamus.

Structure of the Cerebral Cortex. Surfacing the entire cerebrum to a depth of from 1.25 mm. to 4 mm. is a layer composed of nerve-cells, axons and dendrites, neuroglia, blood-vessels, and connective tissue arranged in a most intricate manner. On examination of a cut section of this cortex with a low-power lens it is seen to consist of four or six superimposed layers, alternating white and gray according as fibres or cells predominate.

The outermost layer is a very thin white layer. Internal to it are two gray layers, the outer distinctly gray in color and the inner yellowish red; between these two layers is a white band called the **outer band of Baillarger.** Sometimes the inner of the two cellular layers is further subdivided into two strata by a white stratum, the **inner band of Baillarger.**

The cells of the cortex differ widely in shape and size in different localities, and the lines of demarcation between these groups of cells are often so distinct as to suggest that the division of the cortex into functionally separate areas corresponds with changes in the structural peculiarities of the cells. In general the cell layers are described as:

(a) An outer **Molecular Layer,**

(b) The Layer of **Small Pyramidal Cells.**

(c) The Layer of **Large Pyramidal Cells,**

(d) The Layer of **Polymorphous Cells.**

The cortex is thinnest near the occipital pole; thickest near the summit of the motor area in the parietal lobe. Increase in the bulk of the cortical gray matter is brought about not by augmentation of its thickness but by extension of its total surface area, through deepening of the fissures and sulci. The total number of

cortical nerve-cells has been variously estimated, from 612 millions to 9,000 millions.

The average **weight** of the brain, in the adult male, is about 1380 grams; in the adult female, about 1250 grams. The maximum and minimum may vary considerably from this. The maximum weight is usually reached at about the age of twenty, after which there is a slow decrease. The weight of the brain seems not to be directly related to the degree of intelligence or mental capability, which corresponds rather with the number and depth of the fissures and sulci and consequently with the relative proportion between the amount of cortical gray matter and the total cerebral bulk. Study of a graded series of animal and human brains shows the smooth brain as belonging to those species possessing a low order of intelligence and the highly convoluted brain to the higher orders. A few animals posses brains larger in total bulk than that of man but none are so large in proportion to the bulk of the whole body.

MENINGES OF THE BRAIN AND MEDULLA SPINALIS

Three membranes envelope the brain and medulla spinalis; these are, from without inward, the **dura mater,** the **arachnoid,** and the **pia mater.**

The **Cranial Dura Mater** is a double layer, of fibrous texture, one layer being closely adherent to the interior surfaces of the cranial bones and acting as an internal periosteum, the other investing the brain. The two layers are closely adherent except where they are separated by blood-channels, called sinuses. The outer layer attaches most firmly to the bones along the lines of the sutures. At the base of the skull the dura is reflected outward through various foramina to become continuous with the periosteum on the outer surface of the skull. Four processes, or partitions, are formed by reduplications of the inner, or meningeal, layer of the dura mater and projected into the cranial cavity to divide its contents. These are: the **falx cerebri, falx cerebelli, tentorium cerebelli,** and **diaphragma sellae.**

The **falx cerebri** is a strong, arched, sickle-shaped process which extends down into the longitudinal cerebral fissure. It attaches anteriorly to the crista galli of the ethmoid by a narrow edge, and is fastened posteriorly to the tentorium cerebelli by a wider margin. Its upper margin, which is convex, attaches firmly

to the inner surface of the skull in the median line and contains the superior sagittal sinus; it reaches as far back as the internal occipital protuberance. The inferior margin, concave in outline, is free, and contains the inferior sagittal sinus.

The **falx cerebelli** is a small triangular process of dura mater attached by its posterior margin to the lower half of the vertical portion of the crucial ridge on the inner surface of the occipital bone, and by its upper edge to the under surface of the tentorium cerebelli. It extends forward between the cerebellar hemispheres in the posterior cerebellar notch.

The **tentorium cerebelli** is an arched lamina which covers the cerebellum and upon which rest the occipital lobes of the cerebrum. It is highest in the middle and lowest at its attached circumference. It is fastened behind to the transverse portion of the crucial ridge on the interior of the occipital bone and encloses the transverse sinuses; in front, it attaches to the superior angle of the petrous portion of the temporal bone on either side and there encloses the superior petrosal sinuses. Its anterior margin is free and concave, leaving a large opening, the **incisura tentorii**, for the transmission of the cerebral peduncles. At the apex of the petrous portion of the temporal bone the free anterior and attached lateral borders cross each other and are continued forward to attach to the anterior and posterior clinoid processes of the sphenoid, respectively. The falx cerebri joins the tentorium in the midline in the posterior part, and the straight sinus is enclosed by their union.

The **diaphragma sellae** is a small plate, of circular form, which extends horizontally above the sella turcica of the sphenoid bone and roofs in the hypophysis cerebri, except where a small orifice permits the entrance of the indundibulum.

Structure of Cranial Dura. The cranial dura mater is composed of flattened laminae of white fibrous and yellow elastic tissue. These plates are partially divided by lacunae and blood-vessels into an **endosteal** layer and a **meningeal** layer; the former is the internal periosteum for the cranial bones and carries the blood-vessels which supply them with nourishment; at the magnum foramen it is continuous with the periosteum lining the vertebral canal. The inner layer is lined by a layer of nucleated flattened endothelium.

The dura is supplied with many **arteries.** In the anterior fossa are the anterior meningeal branches of the anterior and posterior

ethmoidal and internal carotid, and a branch from the middle meningeal. In the middle fossa are the middle and accessory meningeal branches of the internal maxillary, a branch from the ascending pharyngeal, which enters the skull through the foramen lacerum; branches from the internal carotid; and a recurrent branch from the lacrimal. In the posterior fossa are branches from the occipital artery, one entering through the jugular foramen and one through the mastoid foramen; the posterior meningeal branch from the vertebral artery; sometimes meningeal branches from the ascending pharyngeal; and a branch from the middle meningeal.

The **veins** anastamose with the diploic veins and terminate in the various sinuses.

The cranial dura receives **nerves** from the semilunar ganglion, from the ophthalmic, maxillary, mandibular, vagus, and hypoglossal nerves, and from the sympathetic by way of the carotid and cavernous plexuses and their branches.

The **Spinal Dura Mater** is continuous with the inner, or meningeal layer of the cranial dura, the outer layer being represented by a true periosteum lining the spinal vertebrae. Externally, the spinal dura is separated from the vertebrae by an **epidural space,** containing loose aerolar tissue and a plexus of veins which corresponds to the sinuses of the cranial dura. Internally, the dura is actually continuous with the arachnoid except where they are separated by a very small amount of fluid for moistening the apposed surfaces; this potential cavity between the two is called **subdural space.** The spinal dura is attached to the margin of the magnum foramen and to the second and third cervical vertebrae; it is fastened by fibrous slips to the posterior longitudinal ligament. The subdural space ends at about the level of the second sacral vertebra and below this the dura closely adheres to the filum terminale and with it descends to the back of the coccyx to blend with the coccygeal periosteum. On each side the dura presents a series of openings for the emergence of the spinal nerves and at each opening the dura is reflected outward as a tubular sheath for the nerve-roots until they have passed through the intervertebral foramina. These sheaths are short above, where the nerve-roots emerge horizontally, but lengthen as the series descends until those which invest the nerve-roots of the cauda equina are very long.

Structure of Spinal Dura. This is similar to that of the meningeal layer of the cranial dura. White fibrous and yellow elastic

tissue is arranged in layers, the fibres being longitudinally disposed in general. A layer of endothelium lines the inner surface. There are few blood-vessels. The nerves are derived chiefly from the recurrent divisions of the spinal nerves.

The **Arachnoid** is a delicate membrane lying between the dura mater externally and the pia mater internally, and enveloping the brain and medulla spinalis. Between it and the pia mater is the **subarachnoid space,** filled with cerebrospinal fluid, and communicating with the ventricular system of the brain by three openings; one, the **foramen of Majendie** in the middle line at the lower end of the roof of the fourth ventricle; and two, the **foramino of Luschka** (*foramina of Key and Retzius*) at the two extremities of the lateral recesses of the fourth ventricle.

The **Cranial Part** of the arachnoid does not follow the convolutions of the brain into the sulci and fissures, except the longitudinal; it is a loose envelope. On the upper surface it is thin and transparent; on the lower surface, somewhat thicker and more opaque; it extends in front of the pons between the two temporal lobes in such a way as to leave a considerable cavity, the **cisterna pontis,** in front of the pons. This cavity contains the basilar artery and is continuous behind with the subarachnoid cavity of the medulla spinalis and with the **cisterna cerebellomedullaris,** a cavity made by the passing of the arachnoid over the space between the medulla and the cerebellar hemispheres. In front the cisterna pontis communicates with the **cisterna interpeduncularis,** which encloses the peduncles and contains the Circle of Willis. Other small cisterns are formed similarly by the passing of the arachnoid directly across hollows in the brain surface.

The **Spinal Part** of the arachnoid is a thin, delicate, tubular investment of the spinal cord, partly separated from the spinal dura by the subdural space. It is continuous above with the cranial arachnoid; below it invests the cauda equina and sends separate sheaths outward upon the nerve-roots.

In structure, the arachnoid is composed of white fibrous and yellow elastic tissue in blended fibre bundles. Its inner and outer surfaces are covered each by a layer of endothelium. It has few blood-vessels but large ones. Its nerves are motor fibres derived from the trigeminal, the facial, and the accessory nerves, and in the spinal arachnoid from the recurrent branches of the spinal nerves.

The **Cerebrospinal Fluid** is a clear, alkaline fluid, having a salty taste, and a specific gravity of 1.007. It is about 98.5% water, the remaining 1.5% being animal and saline material.

The **Arachnoid Villi** (*Pacchionian bodies*) are normal villi of the arachnoid which have increased greatly in size after the third year of life and especially after the seventh, pushing away the dura mater and causing absorption of the bone from pressure. They are found in clusters in the vicinity of the superior sagittal sinus and the adjacent venous lacunae. In old age the encroachment of these villi upon the bone structure may cause considerable thinning of the inner table of the skull; such a calvarium held against transmitted light, may show an extensive viminious arborescence extending for some distance on either side of the midline.

The **Pia Mater.** The pia mater is an incomplete membrane composed of fine areolar tissue supporting a plexus of small blood-vessels. It is covered by an endothelial layer reflected from the numerous processes of the arachnoid which attach to it. All the blood-vessels which enter or leave the nerve system penetrate the pia mater. Processes of pia mater follow these vessels into the nerve system for variable distances as linings for the perivascular spaces.

The **Cranial Pia Mater** closely invests the entire encephalon, dipping into all its fissures and sulci. Invaginations of the pia form the tela choroidea of the third ventricle, the choroid plexuses of the lateral and third ventricles, and the tela choroides and choroid plexus of the fourth ventricle.

The **Spinal Pia Mater** is composed of two layers, the outer one of longitudinal bundles of connective tissue fibres, the inner similar to the cranial pia mater. It closely invests the surface of the cord and is so adherent to it that it cannot be stripped away without leaving a lacerated surface. It sends a process into the ventro-median fissure. At its lower end the spinal pia mater is continued downward as a slender filament, the **filum terminale,** to the back of the coccyx. Because this filum, with its covering of dura mater below the second sacral segment, helps to hold or anchor the spinal cord in movements of the column, it is sometimes called the **central ligament** of the medulla spinalis. Attached along the middle line of the anterior surface is a longitudinal fibrous band, the **linea splendens;** on either side a similar band is called the **ligamentum denticulatum.**

The **Ligamentum Denticulatum** (*dental ligament*) is an incomplete or serrated, fibrous partition separating the anterior from the posterior nerve roots and attaching to the lateral side of the pia mater by a continuous margin and to the dura by a series of twenty-one tooth-like projections. The uppermost process is attached opposite the margin of the foramen magnum, the lowest near the lower end of the medulla spinalis. The dentate ligament serves to hold the cord near the center of the neural canal in lateral flexion of the vertebral column.

THE PERIPHERAL NERVES

All of the structures of the nerve system other than the brain and medulla spinalis are classified as the **peripheral nerve system,** in contradistinction to the **central nerve system** made up of the brain and medulla spinalis, already described. All peripheral nerves are directly or indirectly connected with the central organs and these connections are of such importance as to require study in detail.

The peripheral nerves are divided into three groups; (a) the **cranial nerves;** (b) the **spinal nerves;** and (c) the **sympathetic system.**

THE CRANIAL NERVES

(Cerebral Nerves, Nervi Cerebrales)

The cranial nerves are a series of nerves attached to the brain and transmitted through foramina in the base of the skull. There are twelve pairs, although this grouping is not entirely correct either on functional or embryological grounds; elements described anatomically with one cranial nerve may belong morphologically to another, as will be seen in the detailed description to follow.

The twelve pairs, enumerated in the order of their attachment to the brain from before backward, are as follows:

I. Olfactory
II. Optic.
III. Oculomotor.
IV. Trochlear.
V. Trigeminal.
VI. Abducent.
VII. Facial.
VIII. Acoustic.
IX. Glossopharyngeal.
X. Vagus.
XI. Accessory.
XII. Hypoglossal.

Some of the cranial nerves are purely **afferent** in function; some are purely **efferent;** and some, the **mixed** nerves, contain both afferent and efferent fibres. The area of attachment of a nerve to the surface of the brain is known as its **apparent** or **superficial origin.** The **real origin** of a nerve is the location of the group of nerve cells from which its axons spring; in the case of efferent nerves the real origin is a nucleus, or nidus of cells, embedded in the substance of the brain and from which the axons of the nerve can be traced to their superficial origin; in the case of the afferent nerves the real origin is in a group of cells situated outside the

brain-stem, perhaps as a ganglion on the trunk of the nerve, from which the axons can be traced inward to their superficial origin. Such afferent axons may be followed within the brain until they reach and terminate in relation to a special cell group, or nidus, which is then called the **nucleus of termination,** as that of the efferent nerve is called **nucleus of origin.** The term "deep origin", sometimes used to describe both the nuclei of origin of motor nerves and the nuclei of termination of sensory nerves, is misleading, since in the case of the latter it does not describe an origin at all. In the study of each cranial nerve it will be necessary not only to learn its form, course, and peculiarities outside the brain, but also to follow its fibres within the brain substance and trace out their connections with the organs of the brain. In this way only can a basis be furnished for later study of the physiology of these nerves.

THE OLFACTORY NERVE

(First Cranial Nerve)

The **Olfactory Nerves,** or special sense nerves of **smell,** are formed on either side into nineteen or twenty fibre bundles, or filaments, which arise from a plexiform network situated in the Schneiderian membrane, that is, the mucous membrane lining the superior nasal concha and the corresponding portion of the nasal septum. This membraneous area is called the **pituitary area** or **olfactory area** of the nose. The real origin of the fibres of the olfactory nerve is from the nerve cells known as olfactory cells in this membrane. The fibres are the centrally directed processes of these cells, which are bipolar. The peripherally directed processes, which are very short, are distributed to the mucous membrane in the above described region, and serve as dendrites to gather and transmit to the cells special impressions of odor.

Passing upward in numerous fibre bundles from their real origin, these nerves pierce the cribriform plate of the ethmoid bone in two lines or groups, the **lateral** and the **medial group;** they then enter the under surface of the olfactory bulb, which is their apparent origin, and terminate in the glomeruli of the bulb. In the glomeruli, each fibre ends in a tuft-like terminal which comes into relation with the brush-like end of a dendrite from one of the mitral cells. Several olfactory fibres terminate in each glomerulus and form synapses with dendrites from several mitral cells, which arrangement makes possible the summation of stimuli in mitral cells which enables the detection of very attenuated odors.

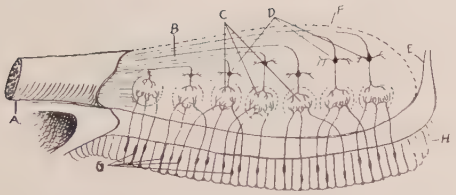

Fig. 36. Diagram of Sagittal Section Through Olfactory Bulb.
A, Olfactory Nerve; B, Nerve Fibres; C, Glomeruli; D, Mitral Cells; E, Frontal Bone; F, Olfactory Bulb; G, Olfactory Cells; H, Epithelium.

The axons of the mitral cells run upward for a short distance and then bend abruptly backward in the deep fibre layer of the bulb to form the olfactory tract. This tract extends backward into the olfactory trigone, just in front of the anterior perforated substance and in the olfactory trigone the axons are divided into three bundles; the **lateral olfactory stria,** the **medial olfactory stria,** and the **intermedial olfactory stria** less marked than the others.

The **lateral olfactory stria** contains the greater number of the fibres comprising the olfactory tract. They curve lateralward and a few end in the olfactory trigone and the anterior perforated substance. Most of them pass into the uncus and there end in the cortex of the hippocampal gyrus. The hippocampal gyrus is the chief cortical center for the olfactory pathway, but many collaterals are given by the lateral stria to the subfrontal cortex.

The **medial olfactory stria** carries fibres to the **parolfactory area** (*Broca's area*), a few to the subcallosal gyrus, and a few to the anterior perforated substance and adjoining part of the septum pellucidum. Some of its fibres pass into the anterior commissure (*pars olfactoria*) to join the olfactory tract of the opposite side, where they pass to the olfactory bulb and serve to unite the bulbs of the two sides.

The **intermedial olfactory stria** is very small and scarcely visible; its fibres end in the anterior perforated substance and in the uncus.

The greater part of the fibres which arise in the mitral cells of the olfactory bulb and traverse the olfactory tract are carried by the lateral olfactory stria to the cortex of the uncus and the hippocampal gyrus.

The olfactory trigone, the anterior perforated substance, and the adjacent part of the septum pellucidum receive many primary olfactory neurons and in turn give origin to secondary olfactory neurons which communicate with the cortex in the subcallosal and hippocampal gyri, and to neurons which pass by way of the fornix

and other somewhat obscure pathways to centers in the brain and spinal cord. Olfactory reflexes are developed by these pathways. Study of the human rhinencephalon is rendered difficult by the fact that whereas, in many animal brains, the rhinencephalon comprises almost the whole of the cerebrum, and the reception of other types of sensory impression for coordination with impressions of smell is somewhat incidental, in man the olfactory portion of the brain has been completely overshadowed by the enormous expansion of the other organs of the neopallium, and many rhinencephalic structures have deteriorated to relative unimportance. In general, the olfactory tracts terminate posteriorly on the under surface of the hemisphere in a triangular or piriform area which spreads out laterally upon the under surface of the temporal lobe and medially on the medial surface of the hemisphere. Some neurons pass directly from the olfactory bulb to the cortex; others terminate in lower olfactory centers which in turn give off new axons to communicate with the cortex.

OUTLINE OF OLFACTORY NERVE

Real Origin—Olfactory cells of pituitary membrane.

Apparent origin—Under surface of olfactory bulb.

Nuclear connection—Glomeruli of olfactory bulb.

Cortical connection—By olfactory tract to medial and under surface of the hemisphere.

Entrance into cranium—Foramina in cribriform plate of ethmoid.

Communications with other nerves—None directly.

Peculiarities—Divided into twenty filaments. Pathway does not decussate.

Distribution—To Schneiderian membrane, upper third of nasal cavity.

This nerve has no direct connection with the vertebral column or spinal nerves. However, the nutrition of the fibres of the olfactory nerve depends directly upon the condition of the cells of origin of these fibres, and this is dominated by the sympathetic nerve elements which control the blood supply to the Schneiderian membrane. The pathway is from the superior cervical ganglion by way of the internal carotid nerve to the spheno-palatine ganglion, and

by the peripheral branches of that ganglion to the Schneiderian membrane. It has been demonstrated that pathological changes in the nasal mucosa will result in loss of the sense of smell and eventually in atrophy of the primary olfactory neurons.

THE OPTIC NERVE

(Second Cranial Nerve)

The **Optic Nerve, nerve of vision,** must be regarded, more than any other nerve, as a direct projection of the brain substance. Embryonically, it develops by a pushing forward of the **optic disk** from the wall of the anterior primary vesicle until a tubular **optic stalk** is formed; the optic disk develops the retina, from the ganglionic cells of which the optic nerve fibres grow backward through the stalk to maintain connection with the cerebrum. The completed optic pathway lends itself to description of the following parts: the **retina,** the **optic nerve,** the **optic chiasma,** the **lower visual centers,** the **optic radiations,** and the **cortical optic centers.**

The Retina. The retina is the nervous tunic of the eye and is the innermost of the three coats. It extends around the posterior four-fifths of the circumference of the eyeball, internal to the choroid coat and in contact with the hyaloid membrane surrounding the vitreous body. Its anterior margin appears to end at the ciliary body in an irregular edge, the **ora serrata,** but a thin membrane is prolonged over the iris and ciliary processes forming the **pars iridica retinae** and the **pars ciliaris retinae.** The retina is soft, semitransparent, and purplish colored in the recent state. Exactly in its center and at a point corresponding to the axis of the eye is an area of oval shape and yellowish color, called the **macula lutea;** here vision is most perfect. A central hollow in the macula lutea is known as the **fovea centralis.** About 1 mm. to the nasal side of the macula lutea is located the **optic disk** at which the optic nerve is attached. The entrance of the arteria centralis retinae at the center of the disk produces there a small area in which visual elements are lacking and which is therefore called the **blind spot.**

The **structure** of the retina is complex. It has an outer pigmented layer and an inner nervous layer, in which the nervous elements are supported by non-nervous, sustentacular fibres. Pigment is absent from the outer layer of the retina in albinos. The nervous layer, or retina proper, is usually described as consisting from within outward of seven layers:

1. Stratum opticum.
2. Ganglionic layer.
3. Inner plexiform layer.
4. Inner nuclear layer.
5. Outer plexiform layer.
6. Outer nuclear layer.
7. Layer of rods and cones.

The nervous elements of the retina are bound together by a framework of fibres called the **sustentacular fibres of Muller**; these begin internally with broad bases which are connected together by their edges to form the **membrana limitans interna.** Adjacent to this membrane is the inner nervous layer, the stratum opticum.

The **stratum opticum** is derived from the expansion of the fibres of the optic nerve; it is thickest at the posterior pole and grows thinner as it approaches the ora serrata. As the optic fibres pierce the lamina cribrosa sclera they lose their medullary sheaths and proceed within the retina as naked axons; these, at the inner surface ramify in plexuses and bundles. The majority of the fibres of the stratum opticum arise as axons of the cells of the ganglionic layer but a few are centrifugal and terminate in the inner plexiform and inner nuclear layers.

The **ganglionic layer** is made up of flask-shaped cells which send their axons into the stratum opticum and give off dendrites which pass into the inner plexiform layer. A single layer of cells makes up this layer except at the macula lutea which has several.

The **inner plexiform layer** is an intermediate layer in the form of an intricate interlacement of dendrites derived from the ganglionic layer with those from the inner nuclear layer.

The **inner nuclear layer** is composed of three types of cells; bipolar cells, horizontal cells, and amacrine cells. Its processes extend inward, some to end in the inner plexiform layer and some in the ganglionic layer, and outward into the outer plexiform layer. The **amacrine cells** of this layer are so called because as yet no axonic processes have been demonstrated as arising in these cells; they are supposed to receive centrifugal fibres from the cerebrum, which may have something to do with controlling the blood-supply of the retina.

The **outer plexiform layer** is a thin intricately interlaced layer of nerve processes; in it the processes of the horizontal cells of the inner nuclear layer are mingled with the outer processes of some of the bipolar cells.

The **outer nuclear layer** consists of several strata of oval nuclear bodies, the **rod granules** and the **cone granules,** which are connected respectively to the rods and cones of the outer layer. The **rod granules,** more numerous than the cone granules, give off a slender process from each end of the cell. The inner process enters the outer plexiform layer and terminates by an expanded extremity in a synapsis with the outer processes of the rod bipolar cells. The outer process is continuous with the inner end of one of the rods of the layer of rods and cones. The **cone granules** are close to the membrana limitans externa, through which they are continuous with the cones of the outer layer.

The Layer of Rods and Cones (*Jacob's membrane*). This layer is made up of two sets of elements, the rods and the cones. The **rods** are the more numerous. They are cylindrical, with their long axis perpendicular to the surface, and of nearly uniform diameter throughout. Each rod is made up of an outer and an inner segment; the visual purple is found only in the outer segment. The **cones** are similar in general structure, and probably in function, to the rods but differ in shape, being more or less flask-shaped, with broad base resting upon the membrana limitans externa and pointed extremity directed toward the choroid coat. Both rods and cones are closely connected with the outer nuclear layer.

Macula Lutea. The structure of the macula lutea differs from that of the remainder of the retina in that the nerve fibres do not form a continuous layer, the ganglionic layer is made up of several strata, and there are no rods but only numerous cones. The fovea centralis shows only the cones, the outer nuclear layer, and a very thin inner plexiform layer.

Blood Supply to the Retina. The **arteria centralis retinae,** the first branch of the ophthalmic artery, runs forward in the dural sheath of the optic nerve to a point about 1.25 cm. back of the eyeball, where it enters obliquely into the substance of the nerve. It enters the retina at the porus opticus, where it produces the blind spot, and at once divides into an upper and a lower branch; each of these subdivides into a lateral and a medial branch (*temporal and nasal*). These branches at first run between the hyaloid membrane

and the retina but soon enter the latter and proceed toward the ora serrata, dividing repeatedly. The divisions give off a minute capillary plexus which extends only to the inner nuclear layer. The macula lutea has several small branches but none enter the fovea centralis. The branches of the arteria centralis retinae are terminal branches and have no anastamosis with each other. A vein accompanies the artery at its entrance. The vasomotor nerve fibres which accompany the central artery are derived from the sympathetic by way of the cavernous plexus; they follow the ophthalmic nerve and its branches.

The Optic Nerve. The term "optic nerve" is usually applied to that part of the optic pathway extending from the retina as far back as the optic chiasma. As a matter of fact the true optic nerve is limited to the ganglionic layer of the retina; the remaining retinal layers may be regarded as a highly specialized sensory end-organ for the reception and transmission to the nerve of light impressions; and the structure which emerges from the back of the eyeball, decussates at the chiasma, and terminates in the optic basal ganglia, is really the optic tract and a part of the brain substance. Morphologically, this is certainly true. Anatomically it is customary, and more convenient, to describe the optic nerve as that part of the pathway which arises in the retina and extends back to the optic chiasma.

The optic nerve is made up chiefly of centripetal fibres (*visual fibres*) arising in the ganglionic layer of the retina and terminating in the lower visual centers, the pulvinar of the optic thalamus, the lateral geniculate body, and the superior colliculus. It contains a few centrifugal fibres which terminate in the amacrine cells of the retina; it also contains fibres, passing centripetally, which are not true visual fibres but which reach the oculomotor nucleus and act as the afferent limb of a reflex arc controlling the movements of the iris and ciliary muscles.

That portion of the optic nerve within the orbit is about 20 mm. to 30 mm. in length and is undulant, to allow for movements of the eyeball. It is attached about 1 mm. medial to the posterior pole of the eye and its direction is medialward and backward to the **optic foramen** through which it enters the cranial cavity. Within the cranial cavity it extends for about 10 mm. along the optic groove to the chiasma. The nerve is covered by an arachnoid coat and a sheath of dura mater derived from those of the brain. These are attached to the sclera at the lamina cribrosa sclera, where the

nerve pierces that coat, and the dura covering the optic nerve becomes continuous with the lining of the orbit. The number of fibres in the optic nerve is unknown, but has been estimated by some observers to exceed 450,000.

The Optic Chiasma. This is a partial decussation of optic nerve fibres. It is a quadrilateral structure resting upon the tuberculum sellae and the anterior part of the diaphragma sellae; from its anterolateral angles the optic nerves diverge; from its posterolateral angles the optic tracts curve backward. The posterior part of the chiasma is occupied by a curving band of fibres, **Gudden's commissure**, which do not enter into the formation of the optic nerve. They are derived from the medial geniculate bodies and pass in both directions so as to connect the medial geniculate bodies of the two sides.

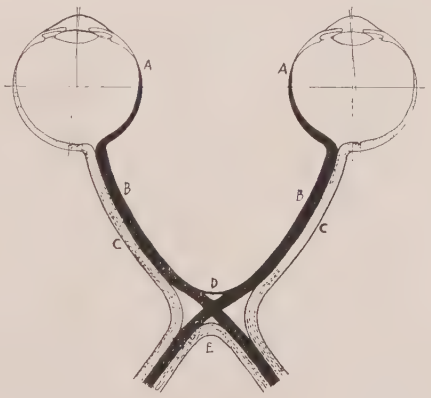

Fig. 37. Schematic Diagram of Hemianopia. A, Nasal Portion of Retina; B, Decussating Optic Nerve Fibres; C, Undecussating Optic Fibres; D, Optic Chiasma; E, Commissure of Gudden.

Within the chiasma, optic fibres from the nasal sides of the two retinae cross with each other. The exact proportion of retinal fibres which decussate is in doubt, but the best opinion seems to be that the fibres from the nasal one-third of each retina cross the median line to continue backward in the opposite optic tract while those from the temporal third of each retina pass through the chiasma uncrossed and continue backward with the optic tract of the same side. The fibres from the macula lutea are differently divided, those from the nasal half of each macula decussating, while those from the temporal half remain uncrossed.

The Optic Tract. Each optic tract therefore contains four groups of fibres: (a) fibres from the temporal two-thirds of the retina of the same side; (b) fibres from the nasal one-third of the opposite retina; (c) fibres from the temporal half of the macula of the same side; and (d) fibres from the nasal half of the opposite macula. The optic tracts emerge from the posterolateral angles of the chiasma and curve backward and outward over the tuber cinereum and anterior perforated space to the cerebral peduncles

and wind obliquely across their under surfaces. Near the lateral geniculate body each tract divides into a **lateral** and a **mesial root.** The mesial, and smaller, band is part of Gudden's commissure and terminates in the medial geniculate body. The lateral band, containing the visual fibres, terminates in the lateral geniculate body, the pulvinar of the optic thalamus, and the superior colliculus; its axons terminate in end-tufts which arborize around the dendrites of the cells of these lower visual centers.

The **Lower Visual Centers** are in the pulvinar of the optic thalamus, the lateral geniculate body, and the superior colliculus. The greater number of visual fibres appear to pass to the lateral geniculate body.

The Optic Radiations. From the lower, or primary, visual centers new axons arise which pass to the cortex; they are gathered near their origin into a fairly compact group called the **optic radiations of Gratiolet,** which pass through the posterior portion of the occipital limb of the internal capsule and then spread out in the occipital lobe to terminate in the cuneus and in the vicinity of the calcarine fissure in the occipital cortex. This area is called the **cortical visual center.**

The superior colliculus, in addition to giving off part of the optic radiations, appears to be an important reflex center for the control of ocular movements. In it, ocular impressions are brought into relation with sensory impressions from other organs through the connections of the superior colliculus with the medial lemniscus and the medial longitudinal bundle.

SUMMARY OF FACTS ABOUT THE OPTIC NERVE

Real Origin—Ganglionic layer of retina.

Apparent Origin—Optic chiasma.

Entrance into Cranium—Optic foramen.

Nuclear Connection—Pulvinar of optic thalamus, lateral geniculate body, superior colliculus.

Cortical Connection—Occipital lobe.

Distribution—To retina.

Nerve Connections—None direct.

Function—Special sense of sight.

THE OCULOMOTOR NERVE

(Third Cranial Nerve)

The **oculomotor nerve** is a purely motor nerve which supplies certain muscles of the eye. Its real origin is from a nucleus, or rather a series of nuclei, situated beneath the floor of the cerebral aqueduct. These nuclei are eight in number and are arranged in two groups, an anterior and a posterior. In the anterior group are two nuclei and in the posterior, six, of which five are duplicated on the two sides of the median line while the sixth is a centrally placed nucleus common to both sides. Each nucleus is related to a particular eye muscle.

The common central nucleus is related to the two medial recti muscles and controls convergence of the eyeballs. Special cell groups supply the sphincter pupillae, tensor choroideae, superior rectus, inferior rectus, levator palpebrae, and inferior oblique muscles. It will be seen that the oculomotor nerve supplies all the extrinsic muscles of the eyeball except the lateral rectus and the superior oblique, and in addition, the intrinsic ocular muscles. The nucleus is not a solid group of cells but is scattered over an area from 6 to 10 mm. long. Its inferior extremity is almost continuous with the trochlear nucleus and is intimately connected, through the medial longitudinal bundle, with the abducent, vestibular, facial, and probably other cranial nerve nuclei.

The oculomotor nucleus receives fibres from the visual area of the occipital cortex through the optic radiations. It also receives fibres from the superior colliculus which have to do with visual reflexes. By way of the pyramidal tract, impulses reach the oculomotor nucleus from the motor area of the cerebral cortex. These fibres decussate in the mid-brain.

Most of the 15,000 fibres which leave the oculomotor nucleus pass to their destination uncrossed but there is a partial decussation, probably involving only those fibres which reach the medial rectus muscle.

From the nucleus, the fibres pass in turn through the tegmentum, the red nucleus, and the medial part of the substantia nigra in a series of curves, convex laterally, and emerge from the oculomotor sulcus on the medial side of the cerebral peduncle. From this superficial origin the nerve passes forward as a single

bundle, covered by sheaths from the pia mater and arachnoid, between the superior cerebellar and posterior cerebral arteries, and pierces the dura mater in front of and lateral to the posterior clinoid process. On its way through the upper part of the cavernous sinus it receives communicating branches from the cavernous plexus of the sympathetic and from the trigeminal nerve. It enters the orbit through the superior orbital fissure by two branches, a superior and an inferior. In the fissure the oculomotor nerve is placed between the two heads of the lateral rectus muscle and below the trochlear nerve and the frontal and lacrimal branches of the ophthalmic, while the nasociliary branch of the ophthalmic lies between its two rami.

The **superior branch** passes medialward over the optic nerve and supplies the superior rectus and the levator palpebrae superior. The **inferior,** and larger, branch separates into three divisions, one of which passes under the optic nerve to the inferior rectus, one to the medial rectus, and the third to the inferior oblique. From the last branch the **short root** is given off to the **ciliary ganglion.** (See page 121.)

Fig. 38.
Diagram of Oculomotor Nerve.

OUTLINE OF OCULOMOTOR NERVE

Real origin—Beneath the floor of the cerebral aqueduct.

Superficial origin—Oculomotor groove on inner side of cerebral aqueduct.

Cortical connection—From the visual area of occipital lobe, and lower part of pre-central area.

Exit from skull—Superior orbital fissure.

Distribution—To all the muscles of the eye except the lateral rectus and superior oblique.

Nerve communications—With cavernous plexus of sympathetic and ophthalmic division of trigeminal in the cavernous plexus.

Function—Efferent (*motor*) to ocular muscles.

Peculiarities—Has partial decussation of fibres. Gives branch to ciliary ganglion.

THE TROCHLEAR NERVE

(Fourth Cranial Nerve)

The **trochlear nerve** is an entirely efferent nerve which supplies the superior oblique muscle, the pulley muscle, hence its name. It is the smallest cranial nerve. It originates in a small nucleus situated beneath the floor of the cerebral aqueduct at the level of the upper end of the inferior colliculus and almost continuous with the lower end of the oculomotor nucleus. The nucleus receives fibres from the visual area of the occipital cortex and communicates freely through the medial longitudinal bundle with the nuclei of the oculomotor, abducent, and facial nerves, and probably with other cranial nerve nuclei. No cortical connection has been demonstrated but there probably exists a pathway similar to that to the oculomotor nerve.

From the nucleus the fibres run downward through the tegmentum and then turn backward into the upper part of the anterior medullary velum where they undergo decussation with those from the opposite side. The nerve then emerges from the side of the frenulum veli just behind the inferior colliculus.

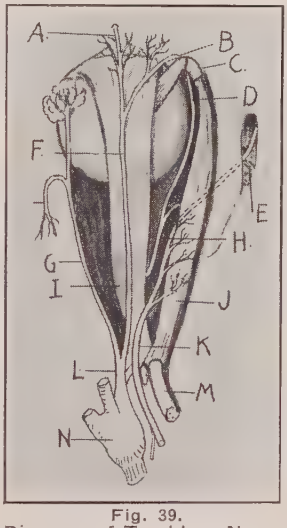

Fig. 39.
Diagram of Trochlear Nerve. A, Supraorbital Nerve; B, Supratrochlear Nerve; C, Trochlea; D, Infratrochlear Nerve; E, Cribriform Plate; F, Frontal Nerve; G, Lacrimal Nerve; H, Nasociliary Nerve; I, Levator Palpabrae Muscle; J, Obliquus Superior Muscle; K, Trochlear Nerve; L, Ophthalmic Nerve; M, Optic Nerves; N, Gasseriam Ganglion.

The nerve crosses the superior peduncle and then curves forward above the pons and around the cerebral peduncle. It pierces the dura mater just behind, and lateral to, the posterior clinoid process, and traverses the cavernous sinus from behind forward between the oculomotor nerve and the ophthalmic division of the trigeminal. It receives branches from the cavernous plexus and from the ophthalmic division of the trigeminal, in the cavernous sinus. It enters the orbit through the superior orbital fissure where it lies above the oculomotor nerve. It then passes medialward and supplies the superior oblique muscle. It sometimes gives a branch to the lacrimal nerve and a recurrent branch passes to the tentorium cerebelli as far as the wall of the cavernous sinus.

OUTLINE OF TROCHLEAR NERVE

Real origin—Beneath the floor of the cerebral aqueduct.

Apparent origin—Lateral side of mid-brain.

Cortical connection—Visual cortex of occipital lobe through optic radiations.

Exit from skull—Superior orbital fissure.

Distribution—To superior oblique muscle.

Function—Efferent (*motor*) to superior oblique.

Nerve communications—Branches from cavernous plexus of sympathetic and from ophthalmic division of trigeminal.

Peculiarity—Smallest cranial nerve.

THE TRIGEMINAL NERVE

(Fifth Cranial Nerve)

The **Trigeminal Nerve** is the largest cranial nerve. It is a mixed nerve, the great sensory nerve to the head and face, and motor to the muscles of mastication. Numerous sensory branches are given to the dura mater, and through these branches referred pains arising in other branches of the trigeminal are often registered as headache.

The motor and sensory roots emerge separately from the pons. The real origin of the motor elements of the trigeminal is in the motor nucleus of the trigeminal situated beneath the lateral angle of the fourth ventricle in the pons, and possibly also in a scattered column of cells at the lateral edge of the central gray matter around the upper end of the fourth ventricle and the lower end of the cerebral aqueduct. This column gives rise to what is known as the **descending or mesencephalic root** of the trigeminal, and there is some doubt as to whether it is a motor or a sensory root; it is generally conceded to be motor.

The **chief motor nucleus,** in the pons, is serially homologous with the motor nucleus of the facial nerve and the nucleus ambiguus, which is the motor nucleus of the vagus and glossopharyngeal nerves. It is connected with the motor area of the cerebral cortex by descending pyramidal tract fibres which decussate before reaching the nucleus. It also communicates, by collaterals and terminals, with the terminal sensory nucleus of the trigeminal of the same side, and to a limited extent with that of the opposite side; with the posterior longitudinal bundle; and it receives the mesencephalic root of the trigeminal.

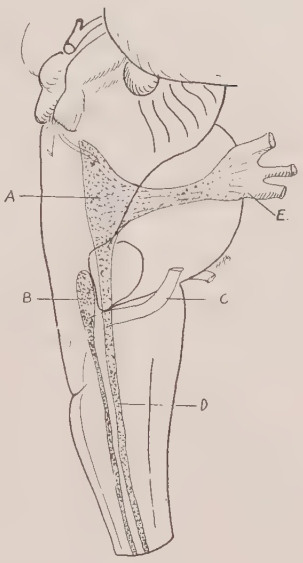

Fig. 40. Schematic Transparency of Brain-Stem, Showing Location of Trigeminal Nerve Nuclei.
A, Sensor Nucleus of Trigeminal; B, Nucleus of Vestibular Nerve; C, Cochlear Nerve; D, Spinal Root of Trigeminal; E, Gasserian Ganglion.

The real origin of the sensory fibres of the trigeminal is in the cells of the **semilunar** (*Gasserian*) **ganglion**, situated on the trunk of the nerve some distance outside the brain. The cells of this ganglion are apparently unipolar, but actually bipolar, giving off two processes which emerge as one from the cell body and then divide in T-shape; the peripherally directed process becomes one of the sensory fibres of the nerve; the centrally directed process passes with the sensory root to enter the pons and come into relation, by a terminal arborization, with the cells of the **terminal sensory nucleus.** This nucleus consists of a **main sensory nucleus,** which is an enlarged upper part, lateral to the motor nucleus and beneath the superior peduncle, and an elongated, descending portion, which descends through pons and medulla and into the substantia gelatinosa of the spinal cord in the cervical region. This column of cells is called the **nucleus of the spinal tract of the trigeminal nerve** and serves as part of a reflex pathway including the trigeminal nerve as an afferent limb and the upper spinal nerves as efferent pathways.

The **main sensory nucleus** contains large and medium-sized cells which give off axons which enter the formatio reticularis and form a bundle, the **central tract of the trigeminal,** which ascends to the ventro-lateral part of the optic thalamus, decussating on the way, at least in part, with the similar tract of the opposite side. In the thalamus, new neurons arise which continue the pathway to the general sensory area of the cerebral cortex. This tract gives off

many collaterals in the medulla, which pass to the motor nuclei of the other cranial nerves to establish reflex pathways. It is probable that the somatic sensory fibres of the facial, the vagus, and the glossopharyngeal nerves terminate in the nucleus of the descending tract of the trigeminal and that their cortical connection is by way of the central sensory pathway of that nerve.

Roots of the Trigeminal. The trigeminal nerve has its superficial origin by two roots, a smaller, medial motor, or efferent root, and a larger, lateral, sensory, or afferent root, from the upper portion of the side of the pons.

The fibres of the motor root are derived from the chief motor nucleus, already described, and from the nucleus of the descending, or mesencephalic root; they join the sensor root at the semilunar ganglion but have no terminals in the ganglion, passing through its under part to continue into the mandibular division of the nerve. The fibres of the sensory root originate in the semilunar ganglion, from which they pass backward below the superior petrosal sinus and tentorium cerebelli to enter the pons. Within the pons they divide into two groups which pass respectively to the chief sensory nucleus and the spinal tract of the trigeminal, already described. The fibres of the sensory root begin to receive their medullary sheaths at about the fifth month of foetal life but medullation is not complete until the third month after birth.

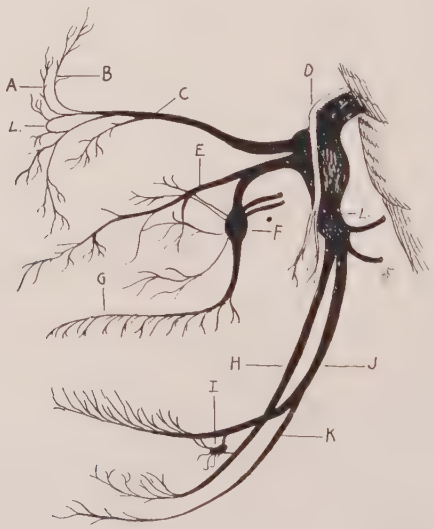

Fig. 41. Drawing of Roots and Branches of Trigeminal Nerve. A, Frontal Nerve; B, Supra-Orbital n.; C, Ophthalmic n.; D, Minor Portion of Trigeminal; E, Infra-Orbital Nerve; F, Spheno-Palatine Ganglion; G, Maxillary Nerve; H, Lingual n.; I, Sub-Maxillary Ganglion; J, Inferior Alveolar n.; K, Mental Branch; L, Otic Ganglion.

The **Semilunar Ganglion** (*Gasserian ganglion*) is a crescentic structure, convex forward, situated in a cavity of the dura mater (*cavum Meckelii*) occupying a curved notch near the apex of the petrous portion of the temporal bone. Medially, it touches the internal carotid artery and the posterior part of the cavernous sinus. The motor root passes beneath the ganglion, in front of and medial to the sensory root and joins the mandibular nerve immediately after its exit from the skull through the foramen ovale.

The semilunar ganglion receives filaments from the carotid plexus of the sympathetic and gives branches to the dura mater of the middle fossa and to the tentorium cerebelli. The ganglion appears to divide, at its convex antero-lateral border, into three large nerves, named from above downward, the **ophthalmic**, the **maxillary**, and the **mandibular.** The upper two are made up exclusively of afferent fibres; the mandibular is joined just outside the foramen ovale by the efferent fibres of the motor root, and is therefore a mixed nerve.

Connected with the branches of the trigeminal are four ganglia: the **ciliary,** which receives a branch from the ophthalmic nerve; the **sphenopalatine**, with which the maxillary nerve communicates; the **otic** and the **submaxillary,** to which branches pass from the mandibular. All these small ganglia receive fibres from three sources: sensory filaments from the trigeminal, motor from other cranial nerves, and sympathetic from the subplexuses of the internal carotid nerve.

The **Ciliary Ganglion** (*ophthalmic or lenticular ganglion*) is a lens-shaped, reddish-gray mass of cells, situated in the orbital fat behind the eyeball and lying between the optic nerve and the lateral rectus muscle, lateral to the ophthalmic artery. It receives a **long,** sensory root from the trigeminal by way of the nasociliary nerve; a **short** motor root from the oculomotor nerve; and a **sympathetic** root from the cavernous plexus. The motor root is also said to contain efferent (*preganglionic*) fibres derived from a part of the oculomotor nucleus in the mid-brain, which form synapses with ciliary ganglion cells, whose postganglionic fibres end in the ciliary and sphincter pupillae muscles.

The ganglion gives off branches, six to ten in number, the **short ciliary nerves** to the iris, ciliary muscle, and cornea. They leave the ganglion in two bundles, of which the lower is the larger,

and run forward in a wavy course, accompanied by the long ciliary nerves. They enter the sclera at the back of the eye and run forward in grooves on its inner surface.

The **Sphenopalatine Ganglion** is related to the maxillary nerve and is the largest of the four sympathetic ganglia connected with the trigeminal nerve. It lies in the pterygopalatine fossa, near the sphenopalatine foramen. It is reddish-gray in color and shaped somewhat like a heart.

The sphenopalatine ganglion receives a **sympathetic** root from the carotid plexus by way of the deep petrosal nerve. Its motor root comes from the nervus intermedius by the greater superficial petrosal nerve and probably carries sympathetic (*preganglionic*) efferent fibres from the medulla; these, when they reach the sphenopalatine ganglion, come into synaptic relation with postganglionic vasomotor and secretory neurons which are distributed to the mucous membrane of the nose, tonsils, uvula, soft palate, roof of the mouth, upper pharynx, and to the upper lip and gums. The sensory root is derived from two sphenopalatine branches of the maxillary division of the trigeminal.

The **deep petrosal nerve** leaves the carotid plexus and passes through the carotid canal on the lateral side of the internal carotid artery. It then enters the cartilage which fills in the foramen lacerum and there unites with the greater superficial petrosal nerve to form the nerve of the pterygoid canal.

The **greater superficial petrosal nerve** leaves the genicular ganglion of the facial nerve, passes through the hiatus in the facial canal and, within the cranium, runs forward under the dura mater on the anterior aspect of the petrous portion of the temporal bone. In the cartilage of the foramen lacerum it unites with the deep petrosal nerve to form the nerve of the pterygoid canal.

The **nerve of the pterygoid canal** (*Vidian nerve*), formed in the foramen lacerum by the union of the greater superficial petrosal and deep petrosal nerves, runs forward through the pterygoid canal, with the pterygoid artery; it is there sometimes joined by a small branch from the otic ganglion. Entering the pterygopalatine fossa it joins the posterior angle of the sphenopalatine ganglion.

Distribution of Branches of the Sphenopalatine Ganglion. The branches are in four groups: (a) **orbital;** (b) **palatine;** (c) **posterior superior nasal;** and (d) **pharyngeal.**

(a) The **orbital branches** are two or three delicate, ascending, filaments which enter the orbit through the inferior orbital fissure and are distributed to the periosteum lining the orbit. Luschka states that some fibres are distributed to the sphenoidal and posterior ethmoidal sinuses.

(b) The **palatine branches** are descending nerves to the roof of the mouth, soft palate, tonsil, and to the membrane lining the nasal cavity. They are chiefly derived from the sphenopalatine branches of the maxillary nerve. They are three: the anterior, middle, and posterior.

The **anterior palatine nerve** passes through the pterygopalatine canal, then through the greater palatine foramen, and runs in a groove on the under surface of the hard palate as far forward as the incisor teeth. On its way through the canal it gives off the **posterior inferior nasal branches** to the membrane over the inferior nasal concha and the inferior and middle meatuses. Its ultimate branches go to the gums, the glands and mucous membrane of the hard palate, and mingle in front with filaments of the nasopalatine nerve. Branches pass to both surfaces of the hard palate.

The **middle palatine nerve** is distributed to the tonsil, uvula, and soft palate.

The **posterior palatine nerve** passes through the pterygopalatine canal and has its exit from a separate opening behind the greater palatine foramen. It is distributed to the soft palate, tonsil and uvula. Both the middle and posterior palatine unite with branches of the glossopharyngeal in forming a plexus around the tonsil.

(c) The **posterior superior nasal branches** enter the back of the nasal cavity by way of the sphenopalatine foramen and are distributed to the mucous membrane lining the nose. The longest branch is called the **nasopalatine nerve.** It passes across the roof of the nasal cavity to the septum and then runs down the septum between the periosteum and the mucous membrane. Through the incisive canal it reaches the roof of the mouth and there communicates with its fellow of the opposite side and with the anterior palatine nerve.

(d) The **pharyngeal nerve** (*pterygopalatine nerve*) is a small nerve which leaves the posterior part of the ganglion, passes through the pharyngeal canal, and is distributed to the mucous membrane of the pharynx, behind the auditory tube.

The Otic Ganglion. The otic ganglion is connected with the mandibular division of the trigeminal. It is small, oval-shaped, and reddish-gray. It lies on the medial surface of the mandibular nerve just outside the foramen ovale. Medially, it is in relation with the cartilaginous portion of the auditory tube; posteriorly, with the middle meningeal artery; and laterally, with the mandibular nerve.

Roots of the otic ganglion are derived from several sources. From the plexus surrounding the middle meningeal artery it receives a **sympathetic** root. The **lesser superficial petrosal nerve** is made up of elements from both the glossopharyngeal and the facial; through this root the otic ganglion receives motor fibres from the facial, while those from the glossopharyngeal are probably sympathetic (*preganglionic*) efferent fibres from the dorsal nucleus or inferior salivatory nucleus of the medulla. Postganglionic continuations of this pathway pass with the auriculotemporal nerve to the parotid gland. Two or three short branches pass from the nerve to the pterygoideus internus to the otic ganglion and may carry a motor, and perhaps a sensor, root.

Branches of Distribution of Otic Ganglion. A filament is given to the tensor veli palatinus and another to the tensor tympani. Fibres pass with the auriculotemporal nerve to the parotid gland.

The Submaxillary Ganglion. This is a small, fusiform, ganglion, placed above the deep portion of the submaxillary gland, on the hyoglossus muscle. It communicates with the lingual nerve by two filaments. Through one of these it receives a branch from the chorda tympani nerve. It also receives fibres from the sympathetic plexus surrounding the external maxillary artery. The chorda tympani fibres are probably preganglionic (*efferent*) fibres from the superior salivatory nucleus in the medulla; their postganglionic continuations are given to the submaxillary gland.

The **branches of distribution** from the submaxillary ganglion arise from its under side and are distributed to the submaxillary gland and its duct and to the mucous membrane of the mouth. Branches also pass, probably, to the lingual nerve for distribution to the sublingual gland.

THE OPHTHALMIC NERVE

The Ophthalmic Nerve is the upper, and smallest, of the three divisions of the trigeminal. It begins at the upper part of the semilunar ganglion in the form of a flattened band, which extends for about 2.5 cm. forward along the lateral side of the cavernous

sinus below the oculomotor and trochlear nerves. At the anterior part of the sinus it divides into three branches; **lacrimal, frontal,** and **nasociliary,** and these three branches enter the orbit through the superior orbital fissure. In the cavernous sinus the ophthalmic nerve is joined by filaments from the oculomotor, trochlear, and abducent nerves, and by fibres from the cavernous plexus of the sympathetic.

This division is entirely sensory (*afferent*) and is distributed to the iris, ciliary body, and cornea; to the lacrimal gland and conjunctiva; to part of the mucous membrane lining the nose; and to the skin of the eyelids, eyebrow, forehead, and nose.

The **Lacrimal Nerve** is the smallest branch of the ophthalmic. As it enters the orbit through the superior orbital fissure it is accompanied by a separate sheath of dura mater. It runs along the upper border of the rectus lateralis muscle, with the lacrimal artery, enters the lacrimal gland and there gives off several filaments, and finally penetrates the orbital septum and terminates in the skin of the upper eyelid. It communicates in the back of the orbit with the zygomatic branch of the maxillary nerve, and on the eyelid with branches of the facial.

The **Frontal Nerve** is the middle and largest branch of the ophthalmic. Entering the orbit through the superior orbital fissure, it passes forward between the levator palpebrae superioris and the periosteum. Halfway across the orbit it divides into **supratrochlear** and **supraorbital** branches. The **supratrochlear nerve** crosses above the pulley of the superior oblique muscle and gives off a branch to the infratrochlear branch of the nasociliary nerve. It then leaves the orbit, curves upward upon the forehead, passes beneath the corrugator and frontalis muscles, and divides into branches which pierce these muscles and are distributed to the skin of the lower and medial part of the forehead. Branches are given to the skin and conjunctiva of the upper eyelid. The **supraorbital nerve** emerges through the supraorbital foramen and there gives off filaments to the upper eyelid. It ascends the forehead and divides into a medial and a lateral branch, which are distributed to the skin of the scalp as far back as the lambdoid suture.

The **Nasociliary Nerve** is the only cranial nerve branch which twice leaves the cranial cavity. It is smaller than the frontal and larger than the lacrimal branch. It enters the orbit by the superior orbital fissure, between the two heads of the rectus lateralis muscle, crosses the optic nerve and runs obliquely beneath the superior

rectus and superior oblique to the medial wall of the orbit. There it re-enters the cranium through the anterior ethmoidal foramen, traverses a shallow groove for a short distance on the lateral part of the cribriform plate of the ethmoid, and then passes down through a slit at the side of the orista galli into the nasal cavity. It loops into the cranium like a stitch sewn through the cribriform plate. It gives **internal nasal** branches to the front of the septum and lateral wall of the nose, and finally emerges as the **external nasal branch** between the lateral nasal cartilage and the lower border of the nasal bone. It then supplies the skin of the ala and tip of the nose. Its branches are: **the long root of the ciliary ganglion,** the **long ciliary nerve,** and the **ethmoidal nerves.**

The **long root of the ciliary ganglion** leaves the nasociliary nerve between the two heads of the rectus lateralis, runs forward lateral to the optic nerve, and enters the posterior-superior angle of the ciliary ganglion; it sometimes communicates with a filament from the cavernous plexus and sometimes with the trochlear nerve.

The **long ciliary nerves,** two or three in number, contain fibres from the superior cervical ganglion to the dilator pupillae muscle. They leave the nasociliary as it crosses the optic nerve and, accompanying the short ciliary nerves from the ciliary ganglion, pierce the sclera, and run forward between sclera and choroid to the iris and cornea.

The **ethmoidal branches** supply the ethmoidal cells and sphenoidal sinus.

The **infratrochlear branch** leaves the nasociliary nerve just before it enters the anterior ethmoidal foramen. It joins, near the pulley of the superior oblique, with a filament from the supratrochlear nerve and then passes to the medial angle of the eye, where it is distributed to the skin of the eyelids and side of the nose, the conjunctiva, lacrimal sac, and caruncula lacrimalis.

THE MAXILLARY NERVE

The Maxillary Nerve, the second division of the trigeminal, is a purely sensory nerve. It arises from the middle of the semilunar ganglion and passes forward as a flattened band. It leaves the skull by the foramen rotundum and is intermediate in position, as well as in size, between the ophthalmic and mandibular nerves. After emerging from the foramen rotundum it becomes firmer and more cylindrical. It crosses the pterygopalatine fossa, slants lat-

eralward behind the maxilla, and passes through the inferior orbital fissure to the interior of the orbit. It then dips into the infraorbital groove and canal in the floor of the orbit and at the end of the canal emerges upon the face by the infraorbital foramen. Beneath that orifice it divides into a leash of branches, which mingle with filaments of the facial in supplying the side of the nose, the lower eyelid, and the upper lip.

Branches. The branches given off by the maxillary nerve during its course are more numerous and more important than its terminals. They are divisible into four groups according to the situation in which they are given off by the main trunk:

In the Cranium	Middle Meningeal
In the Pterygopalatine Fossa	Zygomatic Sphenopalatine Posterior Superior Alveolar
In the Infraorbital Canal	Anterior Superior Alveolar Middle Superior Alveolar
On the Face	Inferior Palpebral External Nasal Superior Labial

The **Middle Meningeal Nerve** is a dural branch given off just after the origin of the maxillary nerve from the semilunar ganglion. It accompanies the middle meningeal artery.

The **Zygomatic Nerve** (*temporomalar, orbital nerve*) is given off in the pterygopalatine fossa and enters the orbit through the inferior orbital fissure. At the back of the orbit it divides into two branches, the **zygomaticotemporal** and **zygomaticofacial.**

The **Zygomaticotemporal branch** traverses a groove in the zygomatic bone on the lateral wall of the orbit and there receives a branch from the lacrimal nerve. It passes through a foramen in the zygomatic bone to enter the temporal fossa, then ascends under the temporalis muscle, pierces the temporal fascia about an inch above the zygomatic arch, and supplies the skin of the side of the forehead and mingles with branches of the facial and the auriculotemporal branch of the mandibular.

The **Zygomaticofacial branch** (*malar branch*) traverses the inferolateral angle of the orbit, emerges upon the face through a foramen in the zygomatic bone, pierces the Orbicularis Oculi, and

is distributed to the skin over the cheekbone. It communicates with the facial nerve and with the inferior palpebral branches of the maxillary.

The **Sphenopalatine branches** are two in number and are given off in the pterygopalatine fossa to descend and join the sphenopalatine ganglion, of which they constitute the sensory root.

The **Posterior Superior Alveolar branches** (*posterior superior dental branches*), usually two in number, leave the trunk of the maxillary nerve just before its entrance into the infraorbital groove. They pass down along the tuberosity of the maxilla, giving several filaments to the gums and to the adjacent mucous membrane of the cheek. They enter the posterior alveolar canals on the temporal surface of the maxilla and pass forward in the substance of the bone, giving three filaments to each molar tooth, which enter the teeth through apertures in the apices of the roots. Filaments are also given to the membrane lining the maxillary sinus, and there is a communication with the middle superior alveolar nerve.

The **Middle Superior Alveolar branch** (*middle superior dental*) supplies the two premolar teeth. It leaves the maxillary nerve in the back part of the infraorbital canal and passes downward and forward in a canal in the lateral wall of the maxillary sinus. It forms a plexus with the posterior and anterior superior alveolar branches.

The **Anterior Superior Alveolar branch** (*anterior superior dental*) leaves the maxillary just before its exit through the infraorbital foramen, descends in a canal in the anterior wall of the maxillary sinus, and separates into branches to supply the incisor and canine teeth. It forms a plexus with the middle superior alveolar branch and gives off a **nasal branch**, which pierces the lateral wall of the nose and supplies the mucous membrane lining the lower part of the inferior meatus and the floor of the nasal cavity; it communicates with branches from the sphenopalatine ganglion.

The **Inferior Palpebral branches** ascend behind the orbicularis oculi and are distributed to the skin and conjunctiva of the lower eyelid, mingling with branches of the facial and zygomaticofacial nerves at the lateral angle of the orbit.

The **External Nasal branches** are distributed to the skin of the side of the nose and of the septum mobile nasi, and communicate with the terminal branches of the nasociliary nerve.

The **Superior Labial branches,** largest and most numerous of the terminal branches of the maxillary, pass beneath the quadratus labii superioris and reach the skin of the upper lip, the mucous membrane of the mouth, and the labial glands. These branches, with some from the facial, form the infraorbital plexus.

THE MANDIBULAR NERVE

The Mandibular Nerve (*inferior maxillary nerve*), the third and lowest division of the trigeminal, is a mixed nerve, containing both motor and sensory elements. It supplies the teeth and gums of the mandible, the skin of the temporal region, the auricula, the lower lip, the lower part of the face and, through the chorda tympani branch from the facial, the anterior two-thirds of the tongue. It is motor to the muscles of mastication.

The mandibular nerve is really made up of two **roots;** a large **sensory** root which arises from the under side of the semilunar ganglion; and a smaller **motor** root, which passes underneath the ganglion and joins the sensory root just after its exit from the foramen ovale. Before dividing into an anterior and a posterior trunk the mandibular nerve gives off a recurrent branch, the nervus spinosus, and a nerve to the pterygoideus internus muscle.

The **Nervus Spinosus,** a recurrent, or meningeal branch, re-enters the skull through the foramen spinosum with the middle meningeal artery. Its two branches, anterior and posterior, accompany the main divisions of the artery and supply the dura mater, while the posterior gives branches to the mucous lining of the mastoid cells and the anterior communicates with the meningeal branch of the maxillary nerve.

The **Internal Pterygoid nerve** is a slender filament which gives off one or two twigs to the otic ganglion and supplies the pterygoideus internus.

The anterior and smaller division of the mandibular nerve is largely motor to the muscles of mastication but is sensory to the skin and mucous membrane of the cheek. Its branches are the **masseter, deep temporal, buccinator,** and **external pterygoid.**

The **Masseter Nerve** passes lateralward in front of the temporomandibular articulation behind the tendon of the temporalis, then crosses the mandibular notch with the masseteric artery, enters the deep surface of the masseter and ramifies that muscle. It has a small branch to the temporomandibular joint.

The **Deep Temporal Nerves,** two in number, pass the upper border of the pterygoideus muscle and enter the deep surface of the temporal muscle. The posterior branch is small. The anterior branch is sometimes given off by the buccinator nerve.

The **Buccinator Nerve** passes forward between the two heads of the pterygoideus extermus and then downward through the lower part of the temporalis, to emerge from beneath the anterior border of the masseter and spread out on the surface of the buccinator muscle. It communicates with the buccal branches of the facial nerve. It gives a branch to the pterygoideus externus, and supplies the skin over the buccinator, and the mucous membrane lining its inner surfaces.

The **External Pterygoid Nerve** often arises in conjunction with the buccinator nerve but is sometimes given off by the anterior division of the mandibular as a separate branch. It enters the deep surface of the muscle.

The posterior and larger division of the mandibular nerve is largely sensory but carries a few motor fibres. It divides into the **auriculotemporal, lingual,** and **inferior alveolar nerves.**

The **Auriculotemporal Nerve** arises by two roots, one on either side of the middle meningeal artery. It runs backward to the medial side of the neck of the mandible, then turns upward with the superficial temporal artery, between the condyle of the mandible and the auricula, beneath the parotid gland. It then ascends over the zygomatic arch and divides into superficial temporal branches. This nerve communicates with the facial nerve and with the otic ganglion. Its branches are the **anterior auricular, branches to the external acoustic meatus, articular** to the temporomandibular joint, **parotid** to the parotid gland, and **superficial temporal.**

The **Lingual Nerve** is distributed to the mucous membrane of the anterior two-thirds of the tongue. After its origin it lies medial to, and in front of, the inferior alveolar nerve beneath the pterygoideus externus muscle. Here it is joined by the chorda tympani branch of the facial nerve, which meets the lingual at an acute angle. The lingual nerve then passes obliquely to the side of the tongue over the superior constrictor of the pharynx, and then traverses the tongue to its tip, lying just beneath the mucous membrane. It communicates with the chorda tympani from the facial, with the inferior alveolar and hypoglossal nerves, and with the

submaxillary ganglion. To the ganglion it gives two or three branches.

Its **branches of distribution** go to the sublingual gland, the mucous membrane of the mouth, the gums, and the mucous membrane of the anterior two-thirds of the tongue. To this area it supplies both general sensory fibres derived from the sensory root of the trigeminal and taste fibres, derived from the chorda tympani.

The **Inferior Alveolar Nerve** is the largest branch of the mandibular. It descends with the inferior alveolar artery, at first beneath the pterygoideus externus and then between the sphenomandibular ligament and the ramus of the mandible, to the mandibular foramen, which it enters. It passes forward through the mandibular canal to the mental foramen, where it divides into the **incisive** and the **mental** branch. Its branches are the **mylohyoid,** to the mylohyoid muscle and the anterior belly of the digastric; the **dental branches,** one to each molar and premolar tooth; the **incisive branch,** which passes through the bone to supply the canine and incisor teeth; and the **mental branch,** which sends filaments to the skin of the chin and the mucous membrane of the lower lip.

OUTLINE OF TRIGEMINAL NERVE

Superficial Origin—By two roots, motor and sensory, from upper part of side of pons.

Real Origin—Of sensory root, cells of the semilunar ganglion. Of motor root, chief motor nucleus in pons, and mesencephalic nucleus.

Divisions—Ophthalmic, Maxillary, and Mandibular.

Exit from Cranium—Ophthalmic by superior orbital fissure. Maxillary by foramen rotundum, Mandibular by foramen ovale.

Distribution—Sensory to skin of face, forehead, eyelids, to conjunctiva, mucous lining of nose and mouth, to gums, teeth, and tongue. Motor to muscles of mastication.

Communications—With oculomotor, trochlear, abducent, facial, glossopharyngeal, hypoglossal and sympathetic. Communicates with four sympathetic ganglia, the ciliary, sphenopalatine, otic, and submaxillary.

Central Connections—With cortex by pyramidal tract and general sensory pathway. With nuclei of origin of most of the cranial and some spinal nerves, by medial longitudinal fasciculus.

THE ABDUCENT NERVE

(Sixth Cranial Nerve)

The **Abducent Nerve** is an entirely motor nerve which is distributed to the rectus lateralis oculi.

The real origin of the fibres of this nerve is in the cells of a nucleus, the **abducent nucleus,** situated beneath the upper part of the floor of the fourth ventricle and beneath the collicula facialis. This nucleus supplies fibres to the lateral rectus of the same side by the abducent nerve and to the medial rectus of the opposite side by fibres which enter the medial longitudinal fasciculus, pass to the oculomotor nucleus, and thence run in the trunk of the oculomotor nerve. The abducent fibres pass from the nucleus downward and forward through the substance of the pons to emerge from a groove (*postpontine groove*) between the lower border of the pons and the pyramid of the medulla oblongata.

It then pierces the dura mater on the dorsum sellae of the sphenoid, runs through a notch below the posterior clinoid process, and traverses the cavernous sinus lateral to the oculomotor nerve. It enters the orbit through the superior orbital fissure, passes between the two heads of the rectus lateralis and enters the ocular surface of that muscle. It receives filaments from the carotid and cavernous plexuses of the sympathetic and one from the ophthalmic nerve.

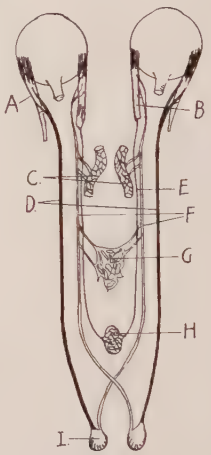

Fig. 42.
Schema of Abducent Nerve.
(*Modified from Gray's Anatomy*)
A, Rectus Lateralis Muscle; B, Rectus Medialis Muscle; C, Carotid Plexus; D, Abducent Nerve; E, Oculomotor Nerve; F, Branch from Abducent Nucleus; G, Cavernous Plexus; H, Oculomotor Nucleus; I, Abducent Nucleus.

OUTLINE OF ABDUCENT NERVE

Real Origin—Abducent nucleus in pons.

Superficial Origin—Postpontine groove.

Cortical Connection—By descending pyramidal tract fibres.

Exit from Cranium—By superior orbital fissure.

Distribution—To rectus lateralis oculi.

Function—Motor.

Communications—With cavernous and carotid plexuses, and ophthalmic nerve.

Peculiarities—Nucleus gives decussating fibres to oculomotor nucleus.

THE FACIAL NERVE

(Seventh Cranial Nerve)

The **Facial Nerve** is a mixed nerve, motor to the muscles of the upper neck and face, except the muscles of mastication, and sensory (*taste*) to the anterior two-thirds of the tongue. Its superficial origin is by two roots, a **motor** and a **sensory root,** which emerge from the groove below the pons, between the olive and the inferior peduncle. The motor root is here more medially placed just back of the abducent nerve, while the sensory root is more lateral, and just anterior to the acoustic nerve. The sensory root is commonly called the **nervus intermedius** (*pars intermedia of Wrisberg, nerve of Wrisberg*), because, in the facial canal, it occupies an intermediate position between the major part of the facial and the acoustic nerve.

The real origin of the **motor root** is in a nucleus deep in the formatio reticularis of the pons, above the nucleus ambiguus, behind the superior olivary nucleus, and medial to the spinal tract of the trigeminal nerve. From this nucleus the fibres pursue a tortuous course, somewhat in the shape of a bent horseshoe, to their point of exit from the pons. They first run backward and medialward toward the floor of the fourth ventricle and at the lower end of the abducent nucleus turn upward close to the middle line; their passage between the abducent nucleus and the floor produces an eminence in the floor of the ventricle called the collicula facialis. At the upper end of the abducent nucleus the facial fibres bend sharply downward and forward and thence pass directly to their point of emergence. This peculiar curve within the pons is called the **genu facialis internum** in contradistinction to the **genu facialis externum,** which is the bend within the facial canal.

The real origin of the **sensory root** is in the cells of the geniculär ganglion, situated on the trunk of the nerve at the genu facialis externum in the facial canal. Like the cells of the semilunar ganglion and those of the dorsal root ganglia of the spinal nerves, these cells give off two processes which appear to emerge as one and divide like a letter T. The centrally directed processes leave the trunk of the facial as the **nervus intermedius** in the internal acoustic meatus and pass to the lower border of the pons as the sensory root. Within the brain they continue into the medulla and terminate in the upper part of the terminal nucleus of the glossopharyngeal nerve

(*the gustatory nucleus*) and in the fasciculus solitarius. The peripherally directed processes of the genicular ganglion cells enter the chorda tympani and greater superficial petrosal nerves.

The **course** of the facial nerve from its superficial origin is at first forward and lateralward in company with the acoustic nerve to the internal acoustic meatus, the two roots remaining separate. Within the meatus the motor root lies in a groove above and anterior to the acoustic nerve and the sensory root between the other two. At the bottom of the meatus the facial nerve enters the facial canal, which it follows to the **stylomastoid foramen** by which it emerges from the skull. The facial canal is a bent channel through the substance of the temporal bone. At first the nerve passes lateralward between the cochlea and vestibule toward the medial wall of the tympanic cavity; it then bends abruptly backward and curves downward behind the tympanic cavity to the stylomastoid foramen. This bend is called the **geniculum**, or genu facialis externum, and the nerve here shows a reddish enlargement, the **genicular ganglion** (*geniculate ganglion*). After leaving the stylomastoid foramen, the facial nerve passes forward through the substance of the parotid gland, crosses the external carotid artery and behind the ramus of the mandible divides into branches which rapidly re-branch and are distributed to the side of the head, face, and upper neck.

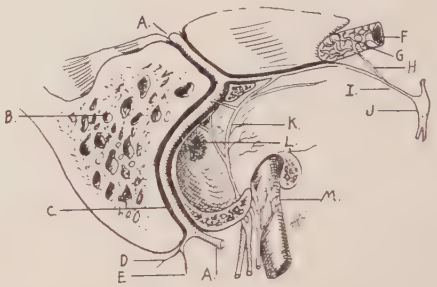

Fig. 43. Diagram of Facial Nerve. A, Facial Nerve; B, Mastoid Bone and Cells; C, Facial Canal; D, To Digastric Muscle; E, To Stylo-Hyoid; F, Carotid Artery; G, Carotid Plexus; H, Deep Petrosal Nerve; I, Pterygoid; J, Spheno-Palatine Ganglion; K, Tensor Tympani; L, Sinua Tympani; M, Carotid Artery.

Branches of Communication. The facial nerve has many communications with other nerves; these may be named in order according to the situation in which they connect with the facial:

In the Internal Acoustic Meatus	With the acoustic nerve.
At the Genicular Ganglion	With the sphenopalatine ganglion by the greater superficial petrosal nerve.
	With the otic ganglion by a branch to the lesser superficial petrosal.
	With the sympathetic on the middle meningeal artery.

In the Facial Canal	With the auricular branch of the vagus.
At the Exit from Stylomastoid Foramen	With the glossopharyngeal. With the vagus. With the great auricular. With the auriculotemporal.
Behind the Ear	With the lesser occipital.
On the Face	With the trigeminal.
In the Neck	With the cutaneous cervical.

The **greater superficial petrosal nerve** (*great superficial petrosal*) contains sensory fibres to be distributed to the mucous membrane of the soft palate, and probably a few motor fibres to form the motor root of the sphenopalatine ganglion. It leaves the facial at the genicular ganglion, passes forward through the hiatus of the facial canal, and runs in a groove on the anterior surface of the petrous portion of the temporal bone, beneath the semilunar ganglion to the foramen lacerum. In the foramen lacerum it is joined by the deep petrosal nerve, from the sympathetic plexus on the internal carotid artery, and the two unite to form the nerve of the pterygoid canal (*Vidian nerve*). This passes forward through the pterygoid canal to the sphenopalatine ganglion.

Branches of Distribution. Two branches are given off within the facial canal: the **nerve to the stapedius** and the **chorda tympani.**

The **chorda tympani** is apparently an aberrant division of the glossopharyngeal, or gustatory, nerve. Its central connection is with the nucleus of that nerve and it shares with the glossopharyngeal the conveyance of the sense of taste, being distributed to the taste buds of the anterior two-thirds of the tongue while the glossopharyngeal supplies the taste buds of the posterior one-third of the tongue and adjacent structures. The chorda tympani is related successively to three cranial nerves; to the glossopharyngeal at their nucleus of termination in the medulla, to the facial as part of its sensory root, and to the trigeminal near its ultimate destination, where the chorda tympani joins its lingual branch.

The chorda tympani leaves the facial nerve behind the tympanic cavity about 6 mm. above the stylomastoid foramen. It runs upward and forward in a canal of its own and enters the tympanic cavity through an opening, the **iter chordae posterius**, in its posterior wall, close to the medial surface of the posterior border of

the tympanum, and level with the upper end of the manubrium of the malleus. It crosses the tympanic cavity from behind forward, lying between the fibrous and mucous layers of the tympanic membrane and there causing a ridge from which it derives the name chorda tympani. It leaves the tympanic cavity through the **iter chordae anterious,** which is a small foramen at the inner end of the petrotympanic fissure, descends on the medial surface of the spina angularis of the sphenoid, and joins the lingual nerve at an acute angle, to be distributed with that nerve to the anterior two-thirds of the tongue.

A few filaments from the motor root are carried by the chorda tympani to the submaxillary ganglion, whence they are distributed to the submaxillary and sublingual glands as excitoglandular fibres. The greater part of its fibres are afferent (*taste*) fibres.

At its exit from the stylomastoid foramen the facial gives off the **posterior auricular nerve** and branches to the digastric and stylohyoid muscles.

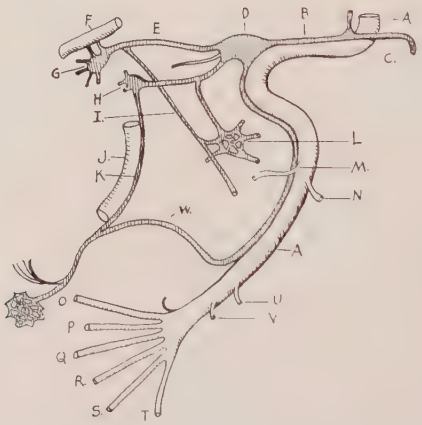

Fig. 44. Diagram of Facial Nerve and Branches. A, Facial Nerve; B, Nervus Intermedius; C, Afferent Division of n. Intermedius; D, Genicular Ganglion; E, Large Superficial Petrosal n.; F, Maxillary n.; G, Spheno-Palatine Ganglion; H, Otic Ganglion; I, Large Deep Petrosal n.; J, Lingual n.; K, Communicating Branches; L, Tympanic Plexus; M, Branch to Stapedius; N, To Auricular Branch of Vagus; O, Temporal; P, Malar; Q, Infra-Orbital; R, Buccal; S, Mandibular; T, Cervical; U, To Digastric; V, To Stylo-hyoid; W, Chorda Tympani n.

The **posterior auricular nerve,** given off near the stylomastoid foramen, runs upward in front of the mastoid process and divides into auricular and occipital branches. The former supplies the auricularis posterior and the intrinsic muscles on the inner surface of the auricula; the latter follows the superior nuchal line of the occipital bone and is distributed to the occipitalis muscle. The **digastric branch** supplies the posterior belly of that muscle, and the

stylohyoid branch, which arises in conjunction with that to the digastric, supplies the stylohyoid muscle.

On the face the facial nerve gives off the **temporal, zygomatic, buccal, mandibular,** and **cervical branches.** The **temporal branches** cross the zygomatic arch and enter the temporal region, communicating with the zygomaticotemporal branch of the maxillary nerve and with the auriculotemporal branch of the mandibular. They are distributed to the frontalis, orbicularis oculi, and the corrugator supercilii, and communicate with the supraorbital and lacrimal branches of the ophthalmic. The **zygomatic branches** cross the zygomatic bone to the lateral angle of the orbit and supply the orbicularis oculi, uniting with filaments from the lacrimal nerve and the zygomaticofacial branch of the maxillary. The **buccal branches** (*infraorbital branches*) are distributed beneath the orbit and around the mouth. They supply the buccinator and orbicularis oris, the quadratus labii superioris, and the small muscles of the nose. The **mandibular branch** supplies the muscles of the lower lip and chin and communicates with the mental branch of the inferior alveolar nerve. The **cervical branch** (*ramus colli*) runs forward beneath the platysma myoides and triangularis and forms a series of arches across the side of the neck over the suprahyoid region. It supplies the platysma and communicates with the cervical cutaneous nerve from the cervical plexus.

OUTLINE OF THE FACIAL NERVE

Real Origin—Motor part from facial nucleus in the pons; sensory part from cells of the genicular ganglion.

Superficial Origin—Postpontine groove, between olive and restiform body.

Exit from Skull—Stylomastoid foramen.

Function—Mixed. Motor to muscles of face, forehead, and upper neck, and sensory (*taste*) to anterior two-thirds of tongue.

Distribution—To all the muscles of the face except muscles of mastication, to upper neck, to anterior two-thirds of tongue.

Communications—With the sympathetic, trigeminal, glossopharyngeal, vagus, and upper cervical nerves.

THE ACOUSTIC NERVE
(Eighth Cranial Nerve)

The **acoustic nerve** is in reality two nerves, the **cochlear nerve** and the **vestibular nerve.** These are usually grouped as one be-

cause of their anatomical contiguity; they differ from each other in origin, central connections, and function, and in the time of their medullation. The eighth nerve is without neurilemma and is soft in texture, being well protected by the situation of most of it within the temporal bone.

The **Cochlear Nerve** (*auditory nerve*), the **nerve of hearing,** has its real origin in the bipolar cells of the spiral ganglion of the cochlea, situated near the inner margin of the osseous spiral lamina. From these cells, peripherally directed processes pass to the organ of Corti, which is a highly specialized receptive mechanism for the transmission to the nerve of impressions made by sound waves. The centrally directed processes pass down the modiolus and then into the lateral end of the internal auditory meatus through the foramina of the tractus spiralis foraminosus or through the foramen centrale. In the meatus the cochlear nerve is closely associated with the vestibular. The two traverse the internal auditory meatus, cross the subarachnoid space, and enter the brainstem at the inferior peduncle and just posterior to the attachment of the facial nerve. The cochlear root is lateral to the vestibular root.

The terminal nuclei of the cochlear division are the **accessory nucleus,** just in front of the inferior peduncle, and the **tuberculum acousticum,** just lateral to it. From the tuberculum acousticum, fibres arise which cross the floor of the rhomboid fossa to the median sulcus as the **striae medullares;** at the sulcus, they dip into the pons to end in relation to the superior olivary nuclei of both sides. Other fibres, direct and crossed, pass to the lateral lemniscus. From the accessory nucleus arises a group of transverse fibres called the **trapezium;** some of these terminate in the superior olivary nucleus or the trapezoid nucleus of the same or the opposite side, while others run directly into the lateral lemniscus of the same or the opposite side.

The **central pathway** of the acoustic nerve is called the **lateral lemniscus,** and lies at the edge of the great sensory pathway, the medial lemniscus. The lateral lemniscus contains fibres derived from both sides; some from the olivary and trapezoid nuclei, some direct from the tuberculum acousticum and the accessory nucleus. The lateral lemniscus contains in its upper part a group of cells, the **nucleus** of the **lateral lemniscus,** which is a terminal station for some fibres of the lateral lemniscus and a station of origin for

others which ascend in the tract. The lateral lemniscus terminates in the medial geniculate body and the inferior colliculus of the opposite side, the **lower auditory centers,** from which new axons arise to continue the pathway to the superior temporal and transverse temporal gyri (*cortical auditory centers*) by way of the **auditory radiations,** which pass through the occipital limb of the internal capsule.

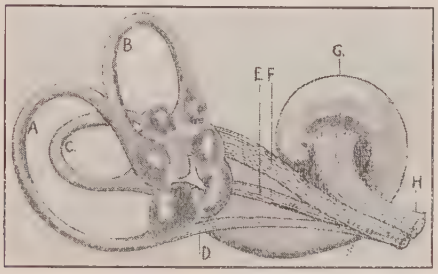

Fig. 45. Terminations of Eighth Cranial Nerve. A, B, C, Semicircular canals; D, Dorsal Ampullar nerve; E, Nerve to saccule; F, Vestibular nerve; G, Cochlea; H, Cochlear nerve.

The **Vestibular Nerve,** the **nerve of equilibrium,** has its real origin in the bipolar cells of the **ganglion of Scarpa,** or **vestibular ganglion,** in the upper part of the outer end of the internal auditory meatus. The peripherally directed processes are distributed through three branches: the upper branch passes through the foramina in the area vestibularis superior and supplies the utricle and the superior and lateral semicircular ducts; the inferior branch passes through the foramina in the area vestibularis inferior and supplies the saccule; the posterior branch traverses the foramen singulare and ends in the ampulla of the posterior semicircular duct.

The centrally directed processes pass with the cochlear nerve through the internal auditory meatus, enter the medulla, and pass between the inferior peduncle and the spinal tract of the trigeminal. They terminate in **Deiter's nucleus** and the **dorsal vestibular nucleus,** with the exception of a few which are continued directly to the cerebellum by the inferior peduncle. Deiter's nucleus gives

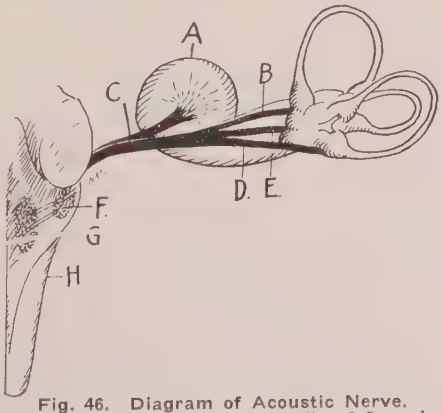

Fig. 46. Diagram of Acoustic Nerve. A, Cochlea; B, Nerve to Ampulla of Superior Semicircular Canal; C, Cochlear Nerve; D, Nerve to Ampulla of Dorsal Semicircular Canal; E, Vestibular Nerve; F, Lateral Vestibular Nucleus; G, Medial Vestibular Nucleus; H, Medulla.

off axons which enter the posterior longitudinal bundle and, dividing into ascending and descending branches, pass to the nuclei of origin of the motor cranial nerves above and to those of the upper part of the spinal cord below. By this pathway co-ordination is established between impressions from the semicircular canals and the muscular actions of the eyes and head. The descending branches are gathered in the cord into the **vestibulospinal** tract. Other fibres from Deiter's nucleus ascend to the thalamus by way of the medial lemniscus of the opposite side, and still others reach the cerebellum by the inferior peduncle. The **dorsal nucleus gives** fibres to the posterior longitudinal bundle to be distributed to the motor cranial nerve nuclei of the opposite side, especially the abducent, trochlear, and oculomotor nuclei, and the motor nuclei of the trigeminal. It is probable that from the thalamus another set of axons completes the equilibratory pathway to the cerebral cortex. Among the most important connections of the vestibular nuclei are those which pass by way of the inferior peduncle to the cortex of the vermis and the roof nuclei of the cerebellum.

OUTLINE OF ACOUSTIC NERVE

Cochlear Division

Real Origin—Spiral ganglion of cochlea.

Superficial Origin—Inferior peduncle.

Distribution—To organ of Corti.

Function—Special sense of hearing.

Exit from Cranial Cavity—Internal orifice of internal auditory meatus. This nerve does not actually leave the skull but ends within the temporal bone.

Communication with Other Nerves—None.

Peculiarity—Does not emerge from the skull.

Cortical Connections—By lateral lemniscus to medial geniculate body and inferior colliculus; thence to cortex by auditory radiations.

Vestibular Division

Real Origin—Ganglion of Scarpa.

Superficial Origin—Postpontine groove, in front of inferior peduncle.

Distribution—To utricle, saccule, and semicircular canals.

Function—Sensory. Nerve of equilibrium.

Nuclei of Termination—Dorsal vestibular nucleus and Deiter's nucleus.

Cortical Connections—To cerebral cortex by way of thalamus, and to vermis and roof nuclei of cerebellum by inferior peduncle.

Communications with Other Nerves—None.

Peculiarities—Does not leave skull.

THE GLOSSOPHARYNGEAL NERVE
(Ninth Cranial Nerve)

The **Glossopharyngeal Nerve** is a mixed nerve, conveying both motor and sensory fibres to the tongue and pharynx. To the posterior part of the tongue it is the special sense nerve of taste, sharing that function with the chorda tympani, which is distributed to the anterior two-thirds of the tongue. To the mucous membrane of the pharynx, fauces, and palatine tonsil it is a general sense nerve. To the pharyngeal muscles it is motor. It carries secretory fibres to the parotid gland.

The **superficial origin** of the ninth nerve is by a series of filaments from the upper part of the dorsolateral groove of the medulla, above the origin of the vagus nerve. It passes lateralward to leave the skull by the **jugular foramen,** in common with the vagus and accessory nerves, which lie behind and medial to it in the foramen. It descends in front of the internal carotid artery as far as the lower border of the stylopharyngeus muscle, then curves forward in an arch on the side of the neck upon the stylopharyngeus and the middle constrictor of the pharynx. It then passes under the hyoglossus muscle to be distributed to the palatine tonsil, the mucous membrane of the fauces and the base of the tongue, and to the mucous glands of the mouth. On the trunk of the nerve are two ganglia, the **superior ganglion** and the **petrous ganglion,** which give origin to its sensory fibres.

The **Superior Ganglion** (*jugular ganglion*) lies in the upper part of the groove by which the nerve passes the jugular foramen. It is a small mass of cells, usually regarded as a detached portion of the inferior ganglion.

The **Petrous Ganglion** (*inferior ganglion*) rests in a depression on the lower border of the petrous portion of the temporal bone.

It is the larger of the two. The cells of the superior and petrous ganglia give off centrally directed processes which enter the medulla and terminate by arborizing around the cells of (a) the **nucleus of the fasciculus solitarius;** (b) a nucleus beneath the ala cinerea; and (c) the **nuclei of the spinal tract of the trigeminal nerve.** The first group are taste fibres, the second sympathetic afferent fibres, and the third somatic sensory fibres. The peripherally directed processes of the cells of the superior and petrous ganglia make up the sensory portion of the glossopharyngeal nerve and its branches.

The real origin of the **somatic motor fibres** is in the **nucleus ambiguus,** in the lateral part of the medulla some distance beneath the floor of the fourth ventricle; this nucleus is continuous with the ventral gray matter of the spinal cord; it gives origin also to the somatic motor fibres of the vagus nerve and to the cranial portion of the accessory nerve. From the nucleus ambiguus the fibres at first pass backward, and then forward and lateralward, to join with the sensory fibres.

Efferent sympathetic fibres arise in the nucleus beneath the ala cinerea and pass with the nerve as preganglionic fibres to the otic ganglion, from which new axons (*postganglionic secretory*) arise to complete the pathway to the parotid gland. Preganglionic motor fibres may also be carried by the glossopharyngeal.

Branches of Communication — The ninth nerve communicates with the **vagus,** the **facial,** and the **sympathetic.**

The branches to the vagus are two in number and are given by the petrous ganglion, one to the auricular branch and one to the jugular ganglion of the vagus. The branch to the facial arises from the trunk of the glossopharyngeal just below the petrous ganglion and joins the facial just after it emerges from the stylomastoid foramen; it is distributed to the posterior belly of the digastric muscle. The petrous ganglion receives a filament from the superior cervical ganglion of the sympathetic.

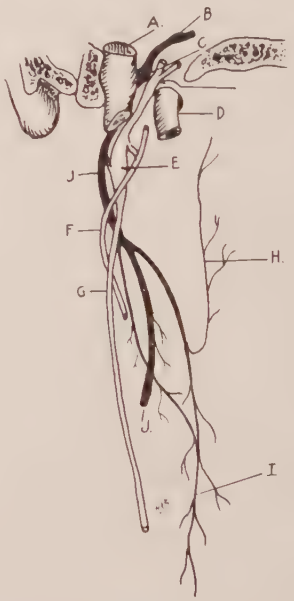

Fig. 47. Diagram of Glossopharyngeal Nerve.

A, Jugular Vein; B, Jugular Ganglion; C, Petrosal Ganglion; D, Carotid Artery; E, Ganglion Nodosum; F, Hypoglossal Nerve; G, Vagus Nerve; H, To Superior Constrictor; I, To Inferior Constrictor; J, Glossopharyngeal Nerve.

Branches of Distribution of the glossopharyngeal are the **tympanic, carotid, pharyngeal, muscular, tonsillar,** and **lingual.**

The **tympanic nerve** (*nerve of Jacobson*) leaves the petrous ganglion and ascends into the tympanic cavity through a small canal on the under surface of the petrous portion of the temporal bone. It divides into branches which form the **tympanic plexus,** which gives off: (a) the lesser superficial petrosal nerve; (b) a branch to the greater superficial petrosal nerve; and (c) branches to the tympanic cavity. The **tympanic plexus** is formed by the nerve of Jacobson, the caroticotympanic nerves from the carotid plexus of the sympathetic, the smaller superficial nerve, and a branch which joins the greater superficial petrosal; it supplies the mucous lining of the tympanic cavity.

The **carotid branches** follow the trunk of the internal carotid to its origin and communicate with the sympathetic and with the pharyngeal branch of the vagus.

The **pharyngeal branches** are three or four branches which unite with the pharyngeal branches of the vagus and sympathetic to form the **pharyngeal plexus** opposite the middle constrictor of the pharynx. This plexus supplies the mucous membrane and muscular coat of the pharynx.

The **muscular branch** supplies the stylopharyngeus muscle.

The **tonsillar branches** form a plexus around the palatine tonsil, from which filaments supply the tonsil, soft palate, and fauces, and communicate with the palatine nerves.

The **lingual branches** are two filaments which supply the taste buds and mucous membrane of the posterior one-third and base of the tongue, and communicate with the lingual branch of the trigeminal.

OUTLINE OF GLOSSOPHARYNGEAL NERVE

Real Origin—Of somatic sensory fibres, superior and petrous ganglia; of somatic motor fibres, nucleus ambiguus; of sympathetic afferent fibres, nucleus beneath ala cinerea.

Exit from Skull—Jugular foramen.

Superficial Origin—Dorsolateral groove of medulla.

Distribution—To tongue, pharynx, fauces, palatine tonsil, and parotid gland.

Function—Mixed; motor to pharynx and stylopharyngeus; sensory (*taste*) to posterior third of tongue; general sense nerve to pharynx, fauces, and tonsil.

Communications—With facial, vagus, and sympathetic.

THE VAGUS NERVE

(Tenth Cranial Nerve)

The **Vagus,** or **Pneumogastric Nerve,** has the most extensive course and distribution of all the cranial nerves. It is a mixed nerve, which passes down the neck and through the thorax and terminates in the abdomen, where it is intricately intermingled with the sympathetic.

Course of the Vagus. Each vagus nerve arises superficially by eight or ten filaments from the side of the medulla oblongata, in the groove between the olive and the inferior peduncle, and just below the superficial origin of the glossopharyngeal nerve. These filaments unite into a flattened band which crosses beneath the flocculus to the jugular foramen, through which the vagus emerges from the skull in company with the glossopharyngeal and accessory nerves. At the jugular foramen the vagus presents the upper of its two ganglia, the **jugular ganglion** (*ganglion of the root*) and just beneath this lies the second enlargement, the **ganglion nodosum** (*ganglion of the trunk*), at the point where the cranial portion of the accessory nerve joins the vagus. The cranial accessory fibres are not terminated at the ganglion but pass on in the trunk of the vagus to be distributed with its pharyngeal and superior laryngeal branches; some of them probably descend to be distributed with the recurrent laryngeal and cardiac branches as well.

Through the neck the course of the two vagus nerves is the same; they descend between the jugular vein and the internal carotid artery to the level of the upper border of the thyroid cartilage, and then between the jugular vein and the common carotid artery to the root of the neck. Below the neck the courses of the two vagi differ materially and they will be separately described.

The **right vagus** passes between the subclavian artery and the innominate vein and downward by the right side of the trachea to the back of the root of the lung. Here, with fibres from the sympathetic, it forms the **posterior pulmonary plexus.** From the lower end of this plexus two cords are gathered and descend on the esophagus and split into filaments which unite with similar filaments from the left vagus to form the **esophageal plexus.** The lower end of the esophageal plexus reunites into a single cord which descends along the back of the esophagus, enters the abdomen at the esophageal opening in the diaphragm, and is distributed to the postero-inferior surface of the stomach, the coeliac plexus, and the lienal plexus.

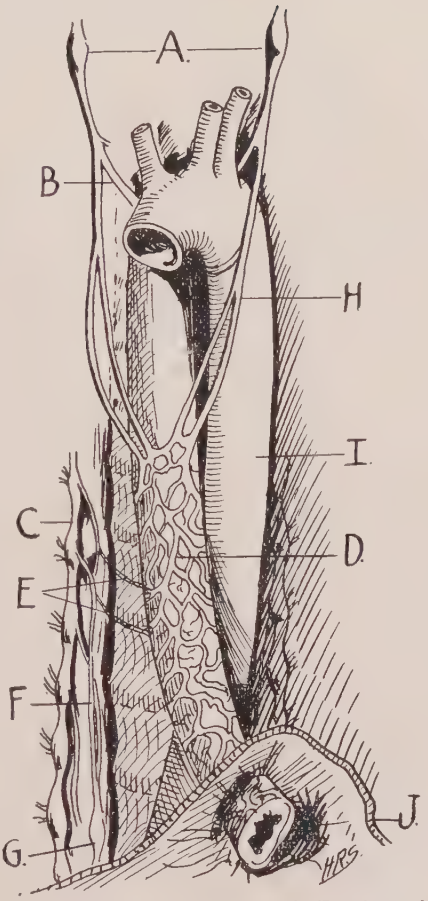

Fig. 48. Vagus Nerves and Esophageal Plexus.
A, Vagus Nerve; B, Branch to Dorsal Pulmonary Plexus; C, Sympathetic Cord (right); D, Esophageal Plexus; E, F, Branches of Sympathetic; G, Splanchnic Ganglion; H, Esophagus; I, Aorta; J, Cut Edge of Diaphragm.

The **left vagus** enters the thoracic cavity behind the left innominate vein and between the left subclavian and left carotid arteries. It crosses the arch of the aorta and passes behind the root of the left lung to form the **posterior pulmonary plexus.** It then runs along the anterior surface of the esophagus where it helps the right vagus to form the **esophageal plexus,** enters the abdomen through the esophageal orifice in the diaphragm, and is distributed to the antero-superior surface of the stomach and to the hepatic plexus.

It will be seen that the vagus nerves, at first descending parallel with each other, undergo a rotatory rearrangement by which right and left nerves become posterior and anterior, and in the abdomen a further twist by which the terminal fibres of each cross the median line, so that the terminals of the right vagus are in the

left half of the upper abdomen and those of the left vagus in the right half.

Ganglia of the Vagus. The **jugular ganglion** is a grayish, spherical, swelling about 4 mm. in diameter; it gives origin to sensory fibres of the vagus. It communicates with the cranial portion of the accessory nerve, with the facial nerve by means of its auricular branch, and receives a twig from the petrous ganglion of the glossopharyngeal and a filament from the superior cervical ganglion. The **ganglion nodosum** also gives origin to sensory fibres of the vagus. It is cylindrical, reddish in color, and measures about 2.5 mm. in length. It is in communication with the hypoglossal, the superior cervical ganglion of the sympathetic, and the loop between the first and second cervical nerves.

Composition of Vagus. Several types of fibres are found in the vagus nerve. There are: (a) **sympathetic afferent fibres;** (b) **somatic afferent fibres;** (c) **taste fibres;** (d) **somatic efferent fibres;** and (e) **sympathetic efferent fibres.**

(a) The sympathetic afferent fibres originate in the jugular ganglion and the ganglion nodosum. The centrally directed processes of these cells enter the medulla with the filaments of the vagus and end by arborizing around the cells of that nucleus beneath the ala cinerea in the upper end of which similar glossopharyngeal fibres terminate.

(b) The somatic afferent fibres are few. They arise from the two ganglia of the vagus, enter the medulla, and join the spinal tract of the trigeminal. The peripheral branches are distributed to the back of the ear and of the external auditory meatus.

(c) The taste fibres end in relation to the fasciculus solitarius in the medulla; they are few in number and are probably aberrant fibres of the glossopharyngeal.

(d) The somatic efferent, or motor, fibres, originate in cells of the nucleus ambiguus, from which also arises the motor root of the glossopharyngeal nerve.

(e) The sympathetic efferent fibres take origin in the dorsal nucleus of the vagus and are classified as sympathetic because they are distributed as preganglionic fibres to sympathetic ganglia scattered through the thorax and abdomen, from which postganglionic fibres pass as: (1) motor fibres to the bronchi; (2) inhibitory

fibres to the heart; (3) motor fibres to esophagus, stomach, small intestines, and bile ducts; and (4) secretory fibres to the stomach and pancreas.

Distribution of Vagus. Thirteen branches are commonly described as given off by the vagus nerve. In the jugular foramen, the **meningeal** and **auricular branches**; in the neck, the **pharyngeal, superior laryngeal, recurrent laryngeal,** and **superior cardiac;** in the thorax, the **inferior cardiac, anterior bronchial, posterior bronchial,** and **esophageal;** in the abdomen, the **gastric, coeliac,** and **hepatic.**

The **meningeal branch** is a recurrent filament given by the jugular ganglion to the dura mater of the posterior fossa of the skull.

The **auricular branch** (*nerve of Arnold*) arises from the jugular ganglion and receives a filament from the petrous ganglion of the glossopharyngeal. It enters the mastoid canal on the lateral wall of the jugular fossa, traverses the substance of the temporal bone, crosses the facial canal about 4 mm. above the stylomastoid foramen and at that point gives off a small branch which joins the facial nerve. It then passes through the tympanomastoid fissure and divides into two branches, one of which joins the posterior auricular nerve, while the other is distributed to the skin of the back of the auricula and the posterior part of the external auditory meatus.

The **pharyngeal branch** leaves the upper part of the ganglion nodosum and is made up chiefly of fibres derived from the cranial portion of the accessory nerve. It passes to the upper border of the constrictor pharyngis medius, where it joins with branches from the glossopharyngeal, sympathetic, and external laryngeal, to form the **pharyngeal plexus.** Branches from this plexus supply the muscles and mucous membrane of the pharynx, and the muscles of the soft palate with the exception of the tensor veli palatini. The pharyngeal branch of the vagus is the chief motor nerve of the pharynx.

The **superior laryngeal nerve** leaves the ganglion nodosum and receives a filament from the superior cervical ganglion of the sympathetic. It descends beside the pharynx and behind the internal carotid artery, and divides into **external** and **internal branches.** The **external branch,** the smaller of the two, supplies the cricothyroid muscle of the larynx, and gives branches to the pharyngeal plexus

and the inferior constrictor muscle of the pharynx, and to the superior cardiac nerve. The **internal branch** accompanies the superior laryngeal artery to the hyothyroid membrane, pierces that membrane, and is distributed to the mucous membrane of the larynx by numerous branches.

The **recurrent nerve** (*inferior laryngeal nerve*) is the chief motor nerve of the larynx and is distributed to all the muscles of the larynx except the cricothyroideus. It carries a few fibres to the mucous membrane of that portion of the larynx below the vocal cords. The course of the two recurrent nerves differs. That on the left side arises from the vagus to the left of the arch of the aorta, winds below the aorta, and then ascends at the side of the trachea; that on the right side arises in front of the subclavian artery, winds back around that vessel, and ascends obliquely beside the trachea and behind the common carotid artery. Both nerves ascend between trachea and esophagus and enter the larynx behind the articulation of cricoid and thyroid cartilages. Each communicates with the internal branch of the superior laryngeal nerve. Branches are given to the deep part of the cardiac plexus, to the esophagus, to the trachea, and to the inferior constrictor of the pharynx.

The **superior cardiac branches** are two or three filaments which arise from the vagus in the neck. The upper branches communicate with the cervical cardiac nerves of the sympathetic and pass to the deep part of the cardiac plexus. The lower branches arise just above the first rib; that on the right goes to the deep part of the cardiac plexus and that on the left to the superficial portion.

The **inferior cardiac branches** arise on the right side both from the trunk of the vagus by the side of the trachea and from the recurrent nerve; on the left side, from the recurrent nerve only. They pass to the deep part of the cardiac plexus.

The **anterior bronchial branches** are two or three small filaments which join with sympathetic fibres to form the **anterior pulmonary plexus.**

The **posterior bronchial branches** are larger and more numerous than the anterior and spread out on the back of the root of the lung. Together with branches from the third and fourth, and sometimes first and second, thoracic ganglia of the sympathetic they form the **posterior pulmonary plexus.** The branches of this plexus

accompany the bronchi and their subdivisions into the substance of the lung.

The **esophageal branches,** given off by both vagi, make up the **esophageal plexus** and give filaments to the back of the pericardium.

The **gastric branches** from the right vagus form the **posterior gastric plexus** and those from the left form the **anterior gastric plexus.** Both plexuses give numerous branches to the stomach.

The **coeliac branches** arise chiefly from the right vagus and are distributed through the coeliac plexus to the pancreas, spleen, kidney, suprarenal glands, and intestines.

The **hepatic branches** arise from the left vagus and are distributed through the hepatic plexus to the liver.

OUTLINE OF VAGUS NERVE

Superficial Origin—Dorsolateral groove of medulla.

Real Origin—Of motor fibres, nucleus ambiguus; of sensory fibres, ganglion nodosum and jugular ganglion.

Nuclei of Termination—Of sympathetic afferent fibres, in nucleus beneath the ala cinerea. Of taste fibres, nucleus of the tractus solitarius; of somatic sensory fibres, nuclei of the spinal tract of the trigeminal.

Function—Mixed.

Distribution—To external ear, pharynx, larynx, heart, bronchi, lungs, esophagus, pericardium, stomach, liver, pancreas, spleen, kidneys, suprarenal glands, and small intestines.

Exit from Skull—Jugular foramen.

Communications—With cranial portion of accessory, facial, glossopharyngeal, sympathetic, and first and second cervical nerves.

THE ACCESSORY NERVE

(Eleventh Cranial Nerve)

The **Accessory Nerve** (*Spinal Accessory Nerve*) is made up of two parts, a **cranial** and a **spinal** part.

The **Cranial,** or **Accessory** portion is the smaller and takes its origin in the cells of the **nucleus ambiguus.** It emerges by four or five filaments from the lower part of the dorsolateral groove of the medulla beneath the origin of the vagus. It runs lateralward to the jugular foramen and there unites for a short distance with the

spinal portion, which, however, quickly re-separates itself. It is connected by slender filaments with the jugular ganglion of the vagus. After traversing the jugular foramen and separating from the spinal portion, the accessory nerve crosses the surface of the ganglion nodosum of the vagus, although none of its fibres originate or terminate therein. It is distributed through the pharyngeal and superior laryngeal branches of the vagus, except for a few fibres which continue in the trunk of the vagus to reach the recurrent nerve and probably the cardiac nerves.

The **Spinal Portions** arise from motor cells in the lateral part of the ventral gray matter of the spinal cord as far down as the nuclei of the fifth cervical nerve. They pass lateralward through the lateral funiculus of the cord to its surface from which they emerge in a series of fibre bundles which unite, as they ascend, to form a single nerve trunk. This trunk ascends between the posterior roots of the spinal nerves and the ligamentum denticulatum, enters the skull through the foramen magnum, crosses to the jugular foramen, and passes through that opening. In the jugular foramen it is separated from the vagus by a fold of the arachnoid but enveloped in the same sheath of dura as the vagus. In the foramen it either receives filaments from the accessory nerve or is united to it for a short distance. After leaving the foramen it descends behind the digastric and stylohyoid muscles to the upper part of the sternomastoid

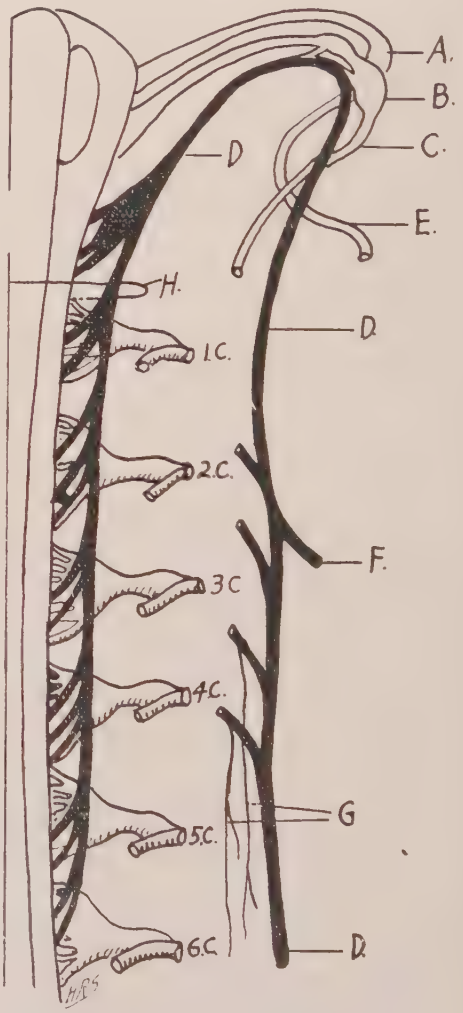

Fig. 49. Diagram of Accessory Nerve.
A, Jugular Ganglion; B, Ganglion Nodosum; C, Vagus Nerve; D, Accessory Nerve; E, Glossopharyngeal Nerve; F, Branch to Sternocleidomastoid Muscle; G, Branch to Trapezius; H, Foramen Magnum.

muscle, which it pierces, and ends in the substance of the trapezius. It communicates with the second, third and fourth cervical nerves. This is a purely motor nerve to the sternomastoid and trapezius muscles.

OUTLINE OF ACCESSORY NERVE

Real Origin—Accessory portion, nucleus ambiguus. Spinal portion, lateral column of ventral gray matter of cord down to fifth cervical segment.

Superficial Origin—Accessory portion, dorsolateral groove of medulla. Spinal portion, lateral aspect of cord.

Exit from Skull—Jugular foramen.

Function—Motor to sternomastoid and trapexious. Motor to pharynx and larynx, inhibitor to heart.

Distribution—To sternomastoid and trapexius and to pharynx, larynx and heart.

Communications—With vagus, and with second, third, fourth, and fifth cervical nerves.

THE HYPOGLOSSAL NERVE

(Twelfth Cranial Nerve)

The **Hypoglossal Nerve** is a purely motor nerve distributed to the muscles of the tongue. Its real origin is from the cells of the **hypoglossal nucleus** in the medulla. This nucleus, which is a continuation of the ventral gray substance of the spinal cord, is about 2 cm. in length; its upper end is level with the **trigonum hypoglossi** and it extends down into the closed part of the medulla and approaches the ventrolateral aspect of the central canal.

The superficial origin of the hypoglossal nerve is by a series of filaments which emerge from the ventrolateral groove of the medulla, between the pyramid and the olive. These filaments are gathered into two bundles which separately penetrate the dura mater and pass through the hypoglossal canal in the occipital bone; this canal may be divided by a slender spicule of bone. Outside the canal, the two divisions of the nerve unite and the combined trunk then descends to a point opposite the angle of the mandible. It is at first deeply situated but lower down becomes superficial below the digastric muscle. It passes under the tendon of the digastric, the stylohyoid, and the mylohyoid, and at the anterior border of the

hyoglossus it communicates with the lingual nerve. It passes through the substance of the genioglossus muscle to the tip of the tongue, giving branches to the muscular substance of the tongue.

The hypoglossal communicates with the ganglion nodosum of the vagus near the skull, and with the pharyngeal plexus. Opposite the atlas it receives a filament from the superior cervical ganglion of the sympathetic and from the loop between the first and second cervical nerves. Near its termination it communicates with the lingual nerve.

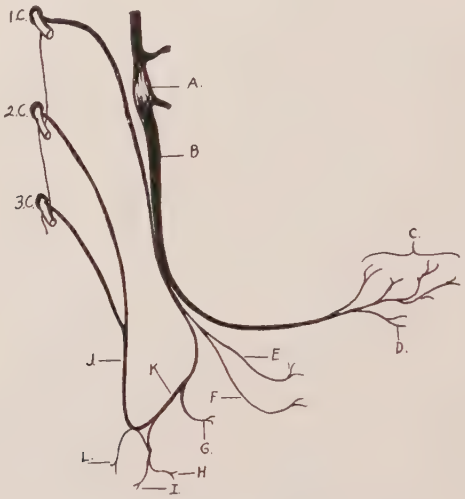

Fig. 50. Diagram of Hypoglossal Nerve.
A, Ganglion Nodosum; B, Hypoglossal Nerve; C, To Muscles of Tongue; D, Lingual Branch; E, Genio-Hyoid Branch; F, Thyro-Hyoid Branch; G, Omo-Hyoid Branch; H, Sterno-Hyoid Branch; I, Sterno-Thyroid Branch; J, Descending Branch of Cervical; K, Descending Branch of Hypoglossal; L, Omo-Hyoid Superior.

Distribution of Hypoglossal Nerve. The branches of the twelfth nerve are (a) **meningeal;** (b) **descending;** (c) **thyrohyoid;** and (d) **muscular.** The **meningeal** branches are several filaments given off in the hypoglossal canal to the dura mater of the posterior fossa of the skull. The **descending** branch is a long slender branch which passes down in front of the occipital artery and joins with the communicantes cervicales from the second and third cervical nerves to form a loop, the **ansa hypoglossi** just below the middle of the neck. Branches from the ansa hypoglossi supply the sternohyoideus, sternothyroideus, and the inferior belly of the omohyoideus; the superior belly of the omohyoideus receives a branch given off by the descending ramus above the loop. The **thyrohyoid** branch arises near the posterior border of the hyoglossus, crosses the

greater cornu of the hyoid bone, and supplies the thyrohyoid muscle. The **muscular** branches supply the styloglossus, hyoglossus, geniohyoideus, and genioglossus.

OUTLINE OF HYPOGLOSSAL NERVE

Real Origin—Hypoglossal nucleus.

Superficial Origin—Ventrolateral sulcus of medulla.

Exit from Skull—Hypoglossal canal.

Function—Motor.

Distribution—To muscles of tongue.

Communications—With vagus, sympathetic, second and third cervical nerves, and lingual branch of the trigeminal.

THE SPINAL NERVES

The peripheral nerves, as previously stated, are divided into three sets, or groups, the **cranial, spinal,** and **sympathetic** groups. The first group has already been described.

The **Spinal Nerves** number thirty-one pairs and are symmetrically attached along the sides of the medulla spinalis. Each spinal nerve is a mixed nerve, motor and sensory. The real origin of its motor elements is in the ventral gray matter of the cord and of its sensory elements, in the ganglia upon the dorsal roots. The spinal nerves leave the vertebral canal through the intervertebral foramina, with exceptions which will be noted. The 31 pairs are divided into groups as follows: Cervical, 8; Thoracic, 12; Lumbar, 5; Sacral, 5; Coccygeal, 1. Each nerve is attached to the side of the medulla spinalis by two **roots,** a ventral and a dorsal.

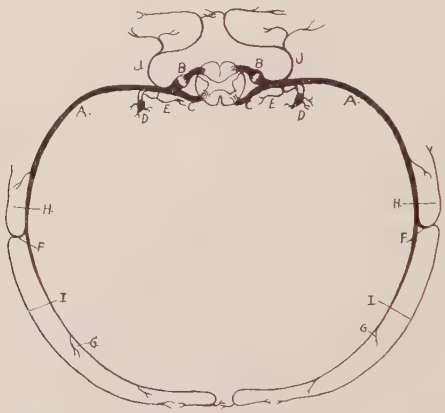

Fig. 51. Diagram of Typical Spinal Nerve.
A, Anterior Primary Division; B, Dorsal Root Ganglion; C, Ventral Root; D, Sympathetic Ganglion; E, Ramus Communicans; F, Lateral Division; G, To Intercostales; H, Posterior Lateral Cutaneous; I, Anterior Lateral Cutaneous; J, Posterior Primary Division.

The **Ventral, Anterior,** or **Motor Root** leaves the ventrolateral surface of the cord in a series of filaments which extend outward, backward, and downward and unite just within the intervertebral foramen into two bundles.

The **Dorsal, Posterior,** or **Sensory Root** is larger than the anterior, except for that of the first cervical nerve, which is smaller than the anterior, and is occasionally absent. The dorsal roots are attached along the dorsolateral sulcus of the cord, by a series of filaments, and extend outward, forward, and downward.

Spinal Ganglia. Each dorsal root presents near the intervertebral foramen a ganglionic enlargement, oval, of reddish color, and proportionate in size to the nerve to which it belongs; the ganglion is bifid medially where it gives off the two bundles of the posterior root. In most cases the ganglia lie in the intervertebral foramina just external to the point at which the nerve penetrates the dura mater; but the ganglia of the first and second cervical nerves are found on the vertebral arches of the first and second cervical vertebræ; those on the sacral nerves lie within the vertebral canal; and that on the coccygeal nerve is within the dural sheath. In some cases part of the cells of a ganglion may be scattered within the nerve root between the ganglion and the surface of the cord.

Three types of nerve cells are found in the spinal ganglia. Most numerous are those which give origin to the sensory fibres of the spinal nerve; these are apparently unipolar, but actually bipolar cells, each of which gives origin to two processes which emerge from the cell closely united and then separate in a T-shaped arrangement; the centrally directed process enters the spinal cord as a sensory root fibre and terminates within the gray matter of the cord or of the medulla, by an arborization around nerve cells; the peripherally directed processes become the sensory, or afferent fibres of the spinal nerve and are directed varying distances to end in relation to various sensory end organs, from which they gather impressions to be transmitted to the cord and brain. Although they have all the anatomic characteristics of axons, they are dendrites in function. The **cells of Dogiel** are small cells whose processes ramify close to the cell and are confined within the ganglion. Multipolar cells similar to those found in sympathetic ganglia are present in the spinal ganglia also.

Each nerve root is covered by a tubular projection of the dura mater and is loosely covered by the arachnoid. Near the intervertebral foramen each root pierces the dura separately, carrying with it a dural sheath which becomes continuous with the sheath of the spinal nerve where the two roots join.

Size and Direction of Roots. The upper four cervical nerves have small roots while those of the lower four cervicals are large. In the cervical region the posterior roots are three times larger than the anterior but the disproportion is less in other regions. An exception is the first cervical nerve, which has a posterior root smaller than its anterior and sometimes entirely absent. The upper

cervical nerve roots extend horizontally outward from the cord to their foramina of exit from the vertebral canal, but as they descend each becomes slightly more oblique downward than the last, so that at the eighth cervical nerve the foramen of exit is lower by the width of one vertebra than the point of attachment.

In the thoracic region the downward slant of the nerve roots increases and each is slightly longer than the last; the lower thoracic roots descend for a distance equal to the width of two vertebrae before they emerge. The thoracic nerve roots, except the first, are small and the posterior barely exceeds the anterior in size.

Largest and longest of the nerve roots are the lumbar and sacral roots, while the coccygeal is the smallest. These roots run vertically downward to their foramina of exit and their length rapidly increases below the termination of the spinal cord at the level of the lower border of the first lumbar vertebra; they are collectively termed **cauda equina** below that level. The largest spinal nerve roots are those attached to the cervical and lumbar enlargements of the cord and which supply the upper and lower limbs.

Composition of Spinal Nerves. Each typical spinal nerve contains fibres of four types: (a) **somatic efferent;** (b) **somatic afferent;** (c) **sympathetic efferent;** and (d) **sympathetic afferent.**

The **somatic efferent** fibres have their origin in the multipolar cells of the ventral gray column of the medulla spinalis and emerge with the ventral roots. They are continuous axons from their origin to their ultimate destination and convey motor impulses to the voluntary muscles.

The **somatic afferent fibres** originate in the bipolar cells of the spinal ganglia as the peripherally directed dendrites of these cells; centrally directed processes of the same cells constitute the dorsal roots. The entire neuron conveys to the spinal cord or brain impressions from the skin, muscles, tendons, etc.

The **sympathetic efferent fibres** are preganglionic fibres which originate in small cells in the lateral column of the gray matter of the medulla spinalis and emerge with the ventral roots. They leave the spinal nerve with the white rami communicantes and terminate in a sympathetic ganglion, sometimes the nearest and sometimes a more distant one; from the ganglion, new (*postganglionic*) axons arise to be distributed in two ways. Some go direct to the viscera to supply their non-straited muscle tissue and secretor epithelium,

while some pass with the gray rami communicantes to the spinal nerve, with which they travel to be distributed to the blood-vessels and secreting glands.

The **sympathetic afferent fibres** arise partly from the multipolar and partly from the bipolar cells of the spinal ganglia. The centrally directed processes of these neurons enter the spinal cord with the dorsal roots and there form synapses with the cells of somatic or sympathetic efferent neurons to complete reflex arcs. The peripherally directed processes traverse the white rami communicantes and, after passing through one or more sympathetic ganglia uninterrupted, terminate in the viscera. The dendrites of the multipolar cells form synapses within the ganglia with the cells of Dogiel, which in turn communicate with the bipolar cells; this mechanism serves for the transmission of some sensory impressions from the sympathetic to the somatic system. The sympathetic fibres are sometimes called **splanchnic** afferent and efferent.

After its formation by the union of its two roots, each spinal nerve emerges from its intervertebral foramen. It at once gives off a small **meningeal branch** (*recurrent branch*) which re-enters the neural canal through the foramen and supplies the vertebrae and their ligaments, and the blood-vessels of the cord and its membranes. This branch contains fibres derived from the sympathetic ganglia by way of the white rami communicantes. Each spinal nerve then divides into an **anterior** and a **posterior primary division,** each of which is mixed, motor and sensory. These will be separately described.

POSTERIOR DIVISIONS OF THE SPINAL NERVES

Most of the posterior divisions are smaller than the anterior. They pass backward from the point of division and most of them divide into medial and lateral branches and supply the muscles and skin of the posterior part of the trunk. Those of the first cervical, fourth and fifth sacral, and coccygeal, do not so divide.

The **posterior division of the first or suboccipital nerve** is larger than the anterior and emerges between the vertebral artery and the upper surface of the posterior arch of the atlas. It enters the suboccipital triangle and supplies the rectus capitis posticus major, the obliquus superior and obliquus inferior, and gives branches to the rectus capitis posticus minor and the semispinalis capitis. A filament joins the posterior division of the second cervical nerve.

The **posterior division of the second cervical nerve** is much larger than the anterior division and largest of all the cervical posterior divisions. Its exit is between the posterior arch of the atlas and the lamina of the epistropheus. It gives a small branch to the obliquus inferior, receives a filament from the first cervical, and then divides into a small lateral and a large medial branch. The **medial branch** is named the **greater occipital nerve.** It ascends obliquely between the obliquus inferior and the semispinalis capitis, and pierces the latter muscle and the trapezius near their attachment to the occipital bone. It receives a filament from the medial branch of the posterior division of the third cervical nerve, and on the back of the head divides into branches which communicate with the lesser occipital nerve and are distributed to the skin of the scalp as far forward as the vortex. It gives branches to the semispinalis capitis. The **lateral branch** gives branches to the splenius, longus capitis, and semispinalis capitis.

The **posterior division of the third cervical nerve** is midway in size between those of the second and fourth. Its **medial** branch passes between the semispinales capitis and cervicis, pierces the splenius and trapezius, and terminates in the skin. It gives a branch under the trapezius, which supplies the skin of the lower part of the back of the head as the **third occipital nerve.** The **lateral** branch frequently joins that of the second cervical.

The **posterior divisions of the lower five cervical nerves** divide into medial and lateral branches. The **lateral branches** supply the iliocostalis, cervicis, longissimus cervicis, and longissimus capitis. The **medial branches** of the fourth and fifth supply the skin in the vicinity of the spinous processes; those of the lower three are small and terminate in the semispinales cervicis and capitis, multifidus, and interspinales.

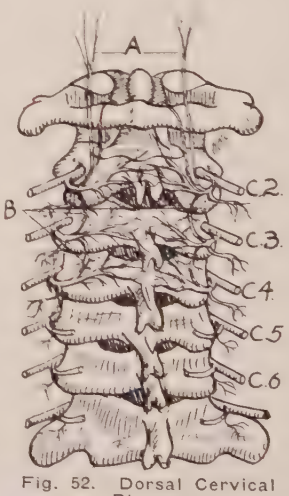

Fig. 52. Dorsal Cervical Plexus.
A, Greater Occipital Nerve; B, Connecting Loops Between Rami From the Dorsal Cervical Plexus.

The **posterior divisions of the Thoracic Nerves** divide into medial and lateral branches. The **medial branches** of the **upper six pass** between the semispinalis dorsi and multifidus, giving branches to these muscles, and supply the skin by the side of the spinous processes. Those of the **lower six** give off occasional filaments to the

skin near the mid-line but are distributed chiefly to the longissimus dorsi and the multifidus. The **lateral branches** increase in size from above downward. They run through or beneath the longissimus dorsi to the space between it and the iliocostales and give branches to both. The lower five or six give off cutaneous branches which penetrate the serratus posticus inferior and latissimus dorsi in a line with the angles of the ribs. The lateral branch of the twelfth thoracic, after sending a filament medialward over the iliac crest, passes down to the skin of the buttock.

The **posterior divisions of the lumbar nerves** give off **medial branches** which run close to the articular processes of the vertebrae and supply the multifidus, and **lateral branches** to supply the sacrospinalis. The upper three lateral branches give off cutaneous nerves which pass through the aponeurosis of the latissimus dorsi at the lateral border of the sacrospinalis and descend across the posterior part of the iliac crest to the skin of the buttock as far down as the great trochanter.

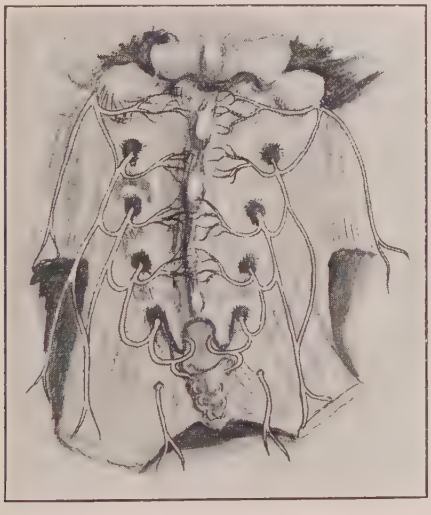

Fig. 53. Dorsal Sacral Plexus.

The **posterior divisions of the sacral nerves** are small and grow smaller from above downward; except the last, they emerge from the posterior sacral foramina. The upper three divide into medial and lateral branches. The **lateral branches** are small and end in the multifidus. The **medial branches** form loops on the back of the sacrum with the lateral branches of the posterior divisions of the last lumbar and fourth sacral, and with each other. From these

loops branches are sent to the back of the sacrotuberous ligament and form a second series of loops under the gluteus maximus. From the second series of loops, branches penetrate the gluteus maximus and supply the skin over the posterior part of the buttock. The posterior divisions of the two lower sacral nerves are small and do not divide into medial and lateral branches; they join with each other and with the coccygeal nerve to form loops upon the back of the sacrum, from which the skin over the coccyx is supplied with filaments.

The **posterior division of the coccygeal nerve** does not divide into medial and lateral branches. It receives a communicating filament from the last sacral, and is distributed to the skin over the coccyx.

ANTERIOR DIVISIONS OF THE SPINAL NERVES

The **anterior divisions of the spinal nerves** are the larger and more important of the two divisions. They give off the communicating branches to the sympathetic which bring the vital organs of the body under the influence of the cerebrospinal system, and they supply the muscles and integument of the antero-lateral portions of the trunk and limbs. In the cervical, lumbar, and sacral regions, they unite to form plexuses; in the thoracic region, they are for the most part separate from each other.

The Cervical Nerves.

The anterior primary division of the **first cervical,** or **suboccipital nerve** emerges from the vertebral canal above the posterior arch of the atlas and passes forward around the lateral aspect of the superior articular process medial to the vertebral artery; it usually descends in front of the rectus capitis lateralis and medial to it. The remaining cervical anterior divisions cross the grooved upper surfaces of the transverse processes of the vertebrae between the anterior and posterior intertransverse muscles.

The anterior divisions of the **upper four cervical nerves** unite to form the **cervical plexus** and each receives a gray ramus communicans from the superior cervical ganglion of the sympathetic. Those of the **lower four cervical nerves,** with a branch from the first thoracic, form the **brachial plexus.** Each receives a gray ramus, those to the fifth and sixth being given off by the middle

cervical ganglion and those to the seventh and eighth by the inferior cervical ganglion.

The Cervical Plexus.

This plexus is a rather complicated arrangement of nerves situated beside the upper four cervical vertebrae in front of the levator scapulae and scalenus medius and covered by the sternocleidomastoideus. The second, third, and fourth cervical nerves divide into upper and lower branches and the branches, with the unbranched first cervical, unite to form three loops. The branches from the plexus are numerous and supply the muscles and skin of the back of the head, neck, upper back, and the diaphragm. They are grouped, for convenience, in two sets, **superficial and deep.** The following table from Gray's Anatomy, indicates the order in which they are given off and the spinal nerves from which each branch is derived.

Superficial			Smaller occipital	C 2
			Great auricular	C 2, 3
			Cutaneous cervical	C 2, 3
			Supraclavicular	C 3, 4
Deep		Communicating	With hypoglossal	C 1, 2
			With vagus	C 1, 2
			With sympathetic	C 1, 2, 3, 4
	Internal	Muscular	Rectus capitis lateralis	C 1
			Rectus capitis anterior	C 1, 2
			Longus capitis	C 1, 2, 3
			Communicantes cervicales	C 2, 3
			Phrenic	C 3, 4, 5
	External	Communicating with accessory		C 2, 3, 4
		Muscular	Sternocleidomastoideus	C 2
			Trapezius	C 3, 4
			Levator scapulae	C 3, 4
			Scalenus medius	C 3, 4

Superficial Branches of the Cervical Plexus.

The **smaller occipital nerve** arises from C2, sometimes C3. It curves and ascends along the posterior border of the sternocleidomastoideus, perforates the deep fascia, and passes along the side of the head behind the ear. It communicates with the greater occipital, the great auricular, and the posterior auricular branch of the facial. It supplies the skin of the back and side of the head and part of the back of the ear.

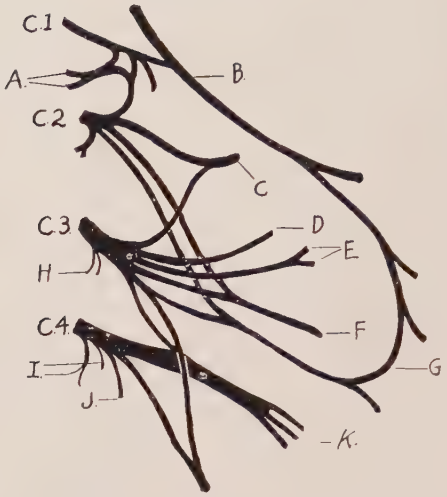

Fig. 54. Schema of Cervical Plexus.
A, To Longus Capitis; B, Hypoglossal Nerve; C.n., Occipitalis Minor; D.n., Auricularis Magnus; E.n., Cutaneous Colli; F, To Trapezius; G, Ansa Hypoglossi; H, To Longus Colli and Levator Scapulae; I, To Longus Colli and Scalenus Medius; J, To Pre-Cervical Muscles; K, To Subscapular Muscles.

The **great auricular nerve,** largest of the ascending branches, arises from C2 and 3. It winds around the posterior border of the sternocleidomastoideus, perforates the deep fascia, ascends beneath the platysma to the parotid gland, and divides into an anterior and a posterior branch. The **anterior branch** supplies the skin of the face over the parotid gland and communicates with the facial. The **posterior branch** (*mastoid branch*) is distributed to the skin over the back of the mastoid process and the back of the ear. A filament reaches the lobule and lower part of the concha. It communicates with the smaller occipital, auricular branch of the vagus, and posterior auricular branch of the facial.

The **cutaneous cervical** nerve is formed by fibres from C2 and 3, curves around the middle of the sternomastoideus, and slants forward under the jugular vein to the anterior border of the muscle. It pierces the deep fascia and divides beneath the platysma into ascending and descending branches. The **ascending branches** pass up to the submaxillary region and unite with the cervical branch of the facial nerve to form a plexus, from which branches supply the skin of the upper and front part of the neck. The **descending branches** supply the skin of the front of the neck as far down as the sternum.

The **suproclavicular nerves** arise from C3 and 4, and descend in the posterior triangle of the neck beneath the platysma and the

deep cervical fascia. Near the clavicle they become cutaneous and are arranged in three groups: anterior, middle, and posterior. The **anterior branches** supply the skin as far as the mid-line and give filaments to the sternoclavicular joint. The **middle** cross the clavicle and supply the skin over the pectoralis major and deltoideus, communicating with the cutaneous branches of the upper intercostal nerves. The **posterior** reach the skin of the upper and posterior part of the shoulder.

Deep Branches of the Cervical Plexus.

The **communicating branches** are those with the sympathetic, the hypoglossal, and the vagus. Each of the upper four cervical nerves receives a gray ramus from the sympathetic which contains vasomotor and secretory fibres which turn outward with the branches of the cervical plexus and are distributed to the bloodvessels and the glands of the skin. Several filaments pass from the loop between the first and second cervical nerves to the vagus, hypoglossal, and sympathetic. The fourth cervical nerve gives a branch to the fifth.

The **muscular branches** supply the longus capitis, rectus capitis anterior, and rectus capitis lateralis.

The **communicantes cervicales** are commonly two filaments, one from the second and the other from the third cervical nerve. They join to form the **descendens cervicalis** which descends lateral to the internal jugular vein, crosses in front of it a little below the middle of the neck, and forms a loop (*ansa hypoglossi*) with the descending ramus of the hypoglossal in front of the sheath of the carotid vessels.

The **Phrenic Nerve** (*internal respiratory nerve of Bell*) is a mixed nerve, containing about twice as many motor as sensory fibres. It has its chief origin from the fourth cervical nerve but receives a branch from the third and one from the fifth. It descends through the neck, slanting across the front of the scalenus anterior and beneath the sternocleidomastoideus, and the inferior belly of the omohyoideus. It then passes in front of the first part of the subclavian artery and crosses the internal mammary artery. In the thorax it descends almost vertically to the root of the lung, then between the pericardium and the mediastinal pleura to the dia-

phragm. There it divides into branches which penetrate the diaphragm and are distributed to its under surface.

The right and left phrenic nerves differ somewhat; the right is deeper, shorter, and more vertical than the left. Each gives branches to the pleura and pericardium, and each is joined at the root of the neck by a filament from the sympathetic. The right nerve is connected with a small **phrenic ganglion,** which gives branches to the ligaments of the liver, the suprarenal glands, and the inferior vena cava. The left nerve sends branches to the phrenic division of the coeliac plexus and a twig to the suprarenal gland of the left side. The phrenic nerve is the motor nerve to the diaphragm.

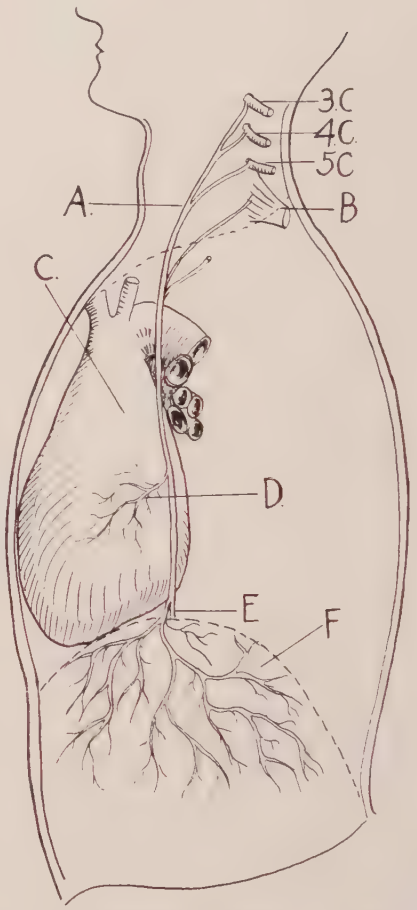

Fig. 55. Schematic Diagram of Phrenic Nerve.
A, Phrenic Nerve; B, Brachial Plexus; C, Pericardium; D, Branch of Phrenic Nerve to Pericardium; E, Branch to Esophagus; F, Esophagus.

The **External Series** of deep branches of the cervical plexus are communicating and muscular. The **communicating branches** reach the accessory nerve in the substance of the sternocleidomastoideus, in the posterior triangle, and beneath the trapezius. The **muscular branches** reach the sternocleidomastoideus, trapezius, levator scapulae, and scalenus medius.

THE BRACHIAL PLEXUS

The brachial plexus extends from the lower part of the side of the neck to the axilla and supplies, through its branches, the shoulder and arm. Its spinal nerve fibres are distributed to muscles and skin, and it carries fibres derived from the sympathetic by way of gray rami communicantes, which supply the blood-vessels and glands.

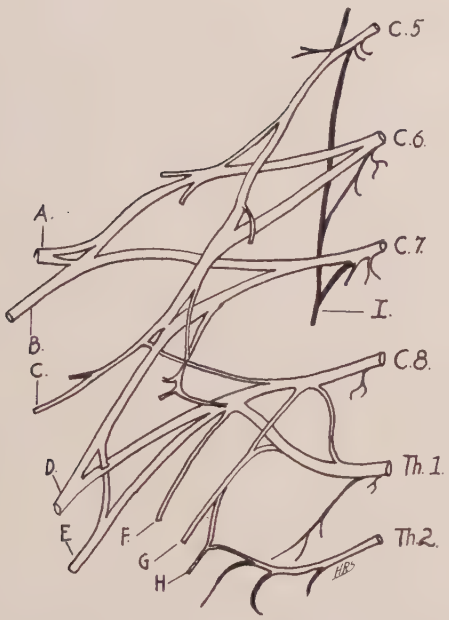

Fig. 56. The Brachial Plexus. A, Axillary Nerve; B, Radial n.; C, Musculo-Cutaneous n.; D, Median n.; E, Ulnar n.; F, Ventral Medial Cutaneous; G, Medial Cutaneous; H, Intercosto-Brachialis; I, Phrenic n.

It is made up of the anterior divisions of the four lower cervical nerves, the greater part of the anterior division of the first thoracic, a branch from the fourth cervical and (*usually*) a branch from the second thoracic. With the exception of these latter branches, the nerves which form it are of fairly equal size. Their arrangement into a plexus is not always precisely the same but the following is the commonest manner of union. The fifth and sixth cervical unite just outside the intervertebral foramen to form one trunk, the **upper trunk.** The seventh cervical at first remains ununited to the others and constitutes the **middle trunk.** The eighth cervical and first thoracic unite to make up the **lower trunk.** As these three trunks pass the clavicle, each splits into an **anterior** and a **posterior division.** The anterior divisions of the upper and middle trunks come together to form the **lateral cord of the brachial plexus,** which runs downward on the lateral aspect of the second part of the axillary artery. The anterior division of the lower trunk descends medial to the axillary artery and is called the **medial cord of the brachial plexus.** The posterior divisions of all three trunks come together to form the **posterior cord of the brachial plexus,** which lies behind the second portion of the axillary artery.

In the neck, the brachial plexus lies in the posterior triangle beneath the skin, platysma, and deep fascia. In the axilla it is at first lateral to the first part of the axillary artery and then the three cords embrace the second part of that artery. At the lower part of the axilla it gives off its terminal branches to the upper limb.

Communications of Brachial Plexus. Each of the five nerves which form the plexus receives a gray ramus from the sympathetic, near the intervertebral foramen. The middle cervical ganglion gives rami to the fifth and sixth cervical nerves and the inferior cervical

ganglion sends rami to the seventh and eighth. That to the first thoracic comes from the first thoracic ganglion and to this ganglion the first thoracic nerve gives a white ramus communicans, the first of the series of white rami which extends down into the lumbar region. The fifth cervical nerve gives a branch to the phrenic nerve.

Branches of Distribution of Brachial Plexus. These are divided into two groups, those given off above and those below the clavicle. The superclavicular branches are:

(1) The **dorsal scapular nerve,** which arises from C5, penetrates the scalenus medius, passes beneath the levator scapulae, and terminates in the rhomboidei.

(2) The **suprascapular nerve,** which leaves the upper trunk (*C5 and C6*), runs lateralward beneath the trapezius and the omohyoideus, and passes through the suprascapular notch into the supraspinatous fossa; it then runs beneath the supraspinatus, and curves around the lateral edge of the spine of the scapula to the infraspinatous fossa. It gives off an articular branch to the shoulder-joint, two branches to the supraspinatus muscle, and two branches to the infraspinatus muscle.

(3) The **nerve to the subclavius** is a slender branch arising from C5 and C6 at their junction. It descends to the subclavius and usually gives a filament to the phrenic nerve.

(4) The **long thoracic nerve** (*external respiratory nerve of Bell*) arises from C5, C6, and C7, and is distributed to the serratus anterior. To this it descends behind the brachial plexus and axillary vessels on the outer surface of the serratus anterior to its lower border.

(5) **Branches to the longus colli and scaleni** arise from the lower four cervical nerves near their exit from the intervertebral foramina.

The **infraclavicular branches** arise from the three cords of the brachial plexus but the fibres of which each is composed have a fairly constant origin in certain spinal nerves. There are three from the lateral cord, five from the medial cord, and five from the posterior cord.

From the **lateral cord** arise the **musculocutaneous, lateral anterior thoracic,** and the **lateral head of the median nerve.**

From the **medial cord** arise the **medial anterior thoracic, medial antibrachial cutaneous, medial brachial cutaneous, ulnar,** and the **medial head of the median nerve.**

From the **posterior cord** arise the **upper subscapular, lower subscapular, thoracodorsal, axillary,** and **radial.**

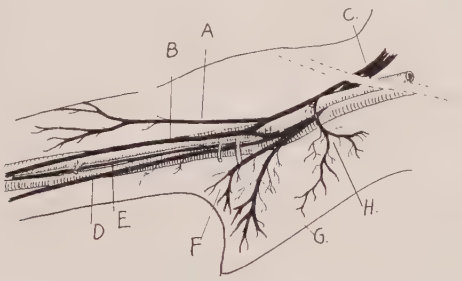

Fig. 57. Axillary Branches of Brachial Plexus. A, Musculo-Cutaneous n.; B, Median n.; C, Brachial Plexus; D, Medial Cutaneous; E, Medial Antibrachial Cutaneous; F, External Anterior Thoracic; G, Internal Anterior Thoracic; H, Posterior Thoracic.

The **musculocutaneous nerve** carries fibres from C5, C6, and C7, and arises from the lateral cord of the brachial plexus opposite the lower border of the pectoralis minor. It penetrates the coracobrachialis muscle and passes between the biceps brachii and the brachialis to the lateral side of the arm; just above the elbow it pierces the deep fascia and then passes into the forearm as the **lateral antibrachial cutaneous nerve.** This passes behind the cephalic vein and divides into a **volar** and a **dorsal branch.** The volar branch passes down the radial side of the forearm to the wrist and supplies the skin of the lateral half of its volar surface; it then descends to end cutaneously in the ball of the thumb. The dorsal branch descends along the dorsal surface of the radial side of the forearm to the wrist and supplies the skin of the lower two-thirds of the dorsolateral surface of the forearm.

The **anterior thoracic nerves** are two, **lateral** and **medial.** They supply the pectoralis major and minor. The **lateral anterior thoracic** carries fibres from C5, C6, and C7, and arises from the lateral cord of the brachial plexus. It crosses the axillary artery to the deep surface of the pectoralis major. The **medial anterior thoracic,** smaller than the lateral, carries fibres from C8 and T1. It enters the deep surface of the pectoralis minor and divides into numerous branches to supply that muscle.

The **subscapular nerves,** an upper and a lower, carry fibres from C5 and C6, and arise from the posterior cord of the plexus. They

supply the subscapularis muscle and the lower ends in the teres major.

The **thoracodorsal nerve** (*middle or long subscapular nerve*) carries fibres from C5, C6, and C7. It arises from the posterior cord. It accompanies the subscapular artery along the posterior wall of the axilla to the latissimus dorsi, and through that muscle to its lower border.

The **axillary nerve** is derived from C5 and C6, and leaves the posterior cord of the plexus. It lies behind the axillary artery and descends to the lower border of the subscapularis. It then winds backward and divides into an **anterior** and a **posterior branch.** The anterior branch winds around the surgical neck of the humerus with the posterior humeral circumflex vessels, to the anterior border of the deltoideus, which it supplies; it gives off cutaneous branches to the skin over the shoulder. The posterior branch supplies the teres minor and the back part of the deltoideus, pierces the deep fascia, and continues as the **lateral brachial cutaneous nerve,** which supplies the skin over the lower two-thirds of the deltoid muscle and that covering the long head of the triceps brachii. An articular filament from the axillary nerve enters the shoulder-joint.

The **medial antibrachial cutaneous nerve** may be traced back to C8 and T1, and is given off by the medial cord of the plexus. It gives off a branch to the skin covering the biceps brachii almost down to the elbow. It then descends the ulnar side of the arm, pierces the deep fascia about the middle of the arm and divides into a **volar** and an **ulnar branch.** The volar branch is the larger. It descends on the front of the ulnar side of the forearm, giving branches to the skin as far as the wrist and communicating with the palmar cutaneous branches of the ulnar nerve.

The **medial brachial cutaneous nerve** (*lesser internal cutaneous nerve; nerve of Wrisberg*) arises from the medial cord and carries fibres from C8 and T1. It is the smallest branch of the brachial plexus, and is distributed to the skin on the ulnar side of the arm. After leaving the medial cord it passes through the axilla at first behind and then medial to the axillary artery, descends to the middle of the arm, pierces the deep fascia, and is distributed to the skin of the lower third of the back of the arm, as far as the elbow.

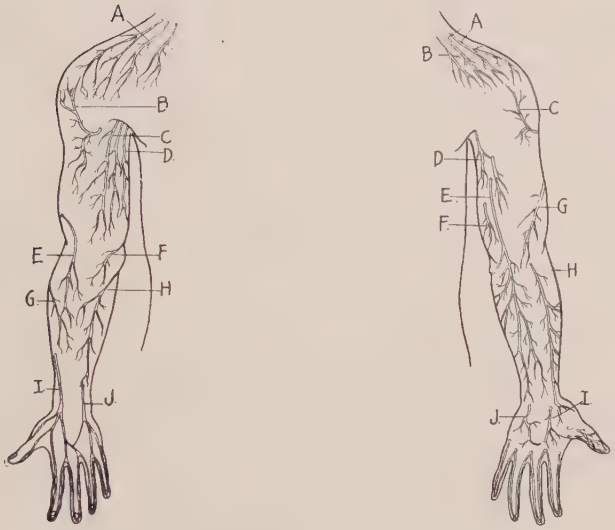

Fig. 58. Superficial Nerves of Arm.

Fig. 1.
A, Acromial n.; B, Circumflex n.; C, Musculospiral n.; D, Intercosto-Humeral n.; E, Musculospiral n.; F, Nerve of Wrisberg; G, External Cutaneous n.; H, Internal Cutaneous n.; I, Radial n.; J, Ulnar n.

Fig. 2.
A, Acromial n.; B, Clavicular n.; C, Circumflex n.; D, Intercosto-Humeral n.; E, Internal Cutaneous n.; F, Nerve of Wrisberg; G, Musculospiral n.; H, External Cutaneous n.; I, Median n.; J, Ulnar.

The **Median Nerve** derives its fibres from C6, C7, C8, and T1. It leaves the brachial plexus by two heads, one from the lateral and one from the medial cord; these embrace the axillary artery and then unite in front of or lateral to that vessel. About the level of the coracobrachialis it crosses the brachial artery and lies on its medial side at the bend of the elbow, where it is placed behind the lacertus fibrosus (*bicipital fascia*) and is separated from the elbow-joint by the brachialis. **In the forearm** it passes between the two heads of the pronator teres and crosses the ulnar artery, and descends beneath the flexor digitorum sublimis to within 5 cm. of the transverse carpal ligament. Here it becomes more superficial and passes behind the transverse carpal ligament into the palm of the hand.

Branches. The median nerve gives off a branch to the pronator teres, but no other in the arm. It sends small twigs to the elbow-joint. In the forearm it gives off **muscular, volar interosseous,** and **palmar** branches. The **muscular** branches leave the nerve near the elbow and supply all the superficial muscles of the front of the forearm except the flexor carpi ulnaris. The **volar interosseus** nerve supplies the deep muscles on the front of the forearm except the ulnar half of the flexor digitorum profundis. It ends below in the pronator quadratus and wrist-joint. The **palmar branch** leaves the

median nerve in the lower part of the forearm. It pierces the volar carpal ligament, and divides into a lateral and a medial branch; the lateral branch is distributed to the skin over the ball of the thumb; the medial branch supplies the skin of the palm, where it communicates with the palmar cutaneous branch of the ulnar.

In the palm of the hand the median nerve rests on the tendons of the flexor muscles and is covered by the palmar aponeurosis and the skin. At the upper part of the palm it becomes larger and flattened and divides into a smaller, lateral, and a larger, medial portion. The **lateral division** sends a short branch to the abductor brevis, the opponens, and the superficial head of the flexor brevis, in the ball of the thumb; it then divides into three **proper volar digital nerves;** two of these supply the sides of the thumb, while the third gives a twig to the first lumbrical muscle and supplies the radial side of the index finger. The **medial division** separates into two **common volar digital nerves.** The first of these gives a small branch to the second lumbrical muscle, and, at the cleft between the index and middle fingers, divides into two proper digital nerves for the adjacent sides of these fingers; the second, at the cleft between the middle and ring fingers, divides into two common digital nerves for the adjacent sides of these fingers. Each proper digital nerve gives off a dorsal branch opposite the proximal end of each phalanx, which joins with the dorsal branch of the superficial ramus of the radial nerve to supply the skin over the dorsal aspect of the last phalanx. At the end of each finger, the proper digital nerve separates into two branches, one of which supplies the pulp of the finger while the other reaches the region under the nail.

The **Ulnar Nerve** derives its fibres from C8 and T1, and arises from the medial cord of the brachial plexus. It is smaller than the median and runs along the medial side of the limb to supply the muscles and skin of the forearm and hand. At its origin it is medial to the axillary artery and lower is medial to the brachial artery to the middle of the arm. There it pierces the medial intermuscular septum, slants across the medial head of the triceps brachii, and descends to the elbow. At the elbow it rests upon the medial epicondyle and enters the forearm between the heads of the flexor carpi ulnaris. In the forearm, it descends along the ulnar side, lying upon the flexor digitorum profundis. It ends about 5 cm. above the wrist by dividing into a dorsal and a volar branch. The ulnar nerve gives off an **articular branch** to the elbow-joint, **muscular, palmar, cutaneous, dorsal,** and **volar branches.** The **muscular** branches

arise near the elbow; one supplies the flexor carpi ulnaris, and the other the ulnar half of the flexor digitorum profundis. The **palmar cutaneous branch** leaves the ulnar nerve about the middle of the forearm and follows the ulnar artery downward. It pierces the volar carpal ligament and ends in the skin of the palm in communication with the palmar branch of the median nerve. The dorsal branch arises about two inches above the wrist and passes backward beneath the flexor carpi ulnaris, perforates the deep fascia, and runs along the ulnar side of the back of the wrist and hand to divide into two dorsal digital branches; one to the ulnar side of the little finger and the other to the adjoining sides of the little and ring fingers. A branch is given to the metacarpal region. The **volar branch** passes lateral to the pisiform bone and divides into a superficial and a deep branch; the superficial branch supplies the palmaris brevis and the skin on the ulnar side of the hand and divides into a proper volar branch to the ulnar side of the little finger, and a common volar digital branch which communicates with the median nerve and terminates in two proper digital branches for adjacent sides of the little and ring fingers. The **deep branch** supplies the three short muscles of the little finger, pierces the opponens digiti quinti and follows the course of the deep volar arch beneath the flexor tendons. In crossing the hand, it supplies all the interossei and the third and fourth lumbricales. It ends in the adductores pollicis and the medial head of the flexor pollicis brevis. It gives filaments to the wrist-joint.

The **Radial Nerve** (*musculospiral nerve*) is in reality a continuation of the posterior cord of the brachial plexus and is the largest branch of the plexus. It carries fibres from C5, C6, C7, C8, and T1. It descends in front of the tendons of the latissimus dorsi and teres major and behind the first part of the axillary artery and upper part of the brachial artery, and then winds from the medial to the lateral side of the humerus in a groove between the medial and lateral heads of the triceps brachii. It perforates the lateral intermuscular septum and passes between the brachialis and brachioradialis to the front of the lateral epicondyle, where it divides into a superficial and deep branch. The radial nerve gives off **muscular, cutaneous, superficial,** and **deep branches.**

The **muscular** branches are medial, posterior and lateral. The **medial** supply the long heads of the triceps brachii. The **posterior,** a large branch, arises from the radial nerve in the groove and divides into filaments to supply the medial and lateral heads of the

triceps brachii and the anconaeus. The **lateral** branches are distributed to the brachioradialis, extensor carpi radialis longus, and the lateral part of the brachialis.

The **cutaneous** branches are the posterior brachial cutaneous and the dorsal antibrachial cutaneous. The **posterior brachial cutaneous nerve** arises in the axilla with the medial muscular branch. It passes through the axilla to its medial side, supplying the skin on the dorsal surface of the arm almost as far down as the olecranon. The **dorsal antibrachial cutaneous nerve** pierces the lateral head of the triceps brachii at its attachment to the humerus. Its **upper** branch passes to the front of the elbow and is distributed to the skin of the lower half of the arm. The **lower** branch perforates the deep fascia below the insertion of the deltoideus, and descends along the lateral side of the arm and elbow, and then along the back of the forearm to the wrist. It supplies the skin along its course and joins with the dorsal branch of the lateral antibrachial cutaneous nerve.

The **superficial branch of the radial nerve** arises by the division of the radial in front of the lateral epicondyle, and runs along the front of the radial side of the forearm to the junction of its middle and lower thirds. It is associated with the radial artery in its course down to a point a little less than three inches above the wrist, where it leaves the artery, passes beneath the tendon of the brachioradialis, pierces the deep fascia and separates into two branches. The lateral branch, smaller than the medial, supplies the skin of the radial side and ball of the thumb. The medial branch communicates above the wrist with the dorsal branch of the lateral antibrachial cutaneous, and, on the back of the hand, with the dorsal branch of the ulnar nerve. It then divides into four digital nerves; the first to the ulnar side of the thumb; the second to the radial side of the index finger; the third to the adjacent sides of the index and middle fingers; and the fourth to the adjacent sides of the middle and ring fingers.

The **deep branch of the radial nerve** winds to the back of the forearm around the lateral side of the radius, and extends downward between the superficial and deep layers of muscles, to the middle of the forearm. It descends as the **dorsal interosseous nerve,** on the interosseous membrane, in front of the extensor pollicis longus, to the back of the carpus. Here it presents a gangliform enlargement which gives filaments to the carpal ligaments and

joints. It supplies all the muscles on the radial side and dorsal surface of the forearm, except the anconaeus, brachioradialis, and extensor carpi radialis longus.

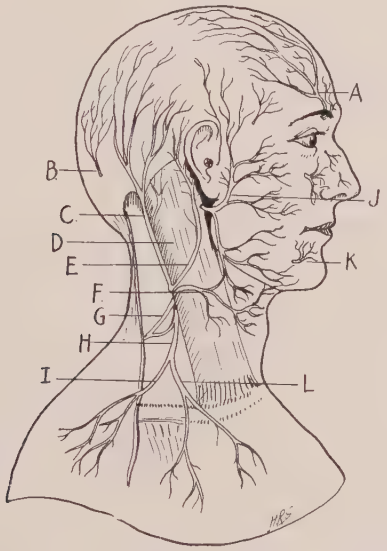

Fig. 59. Schema of Superficial Nerves of Neck and Face. A, Superficial Frontal n.; B, Greater Occipital n.; C, Lesser Occipital; D, Sternocleidomastoid Muscle; E, Posterior Auricular n.; F, Superficial Cervical n.; G, Accessory n.; H, Supraclavicular n.; I, Dorsal Branch of Supraclavicular Nerve n.; J, Superficial Facial n.; K, Mental n.; L, Ventral Division of Supraclavicular n.

THE THORACIC NERVES

The thoracic nerves number twelve pairs. The anterior primary divisions of these nerves are larger and more important than the posterior divisions. Eleven of them are situated between the ribs and are termed **intercostal nerves;** the twelfth is placed below the twelfth rib and is sometimes called the **subcostal nerve.** Each is connected with the adjacent sympathetic ganglion by a gray and a white ramus communicans. Each intercostal nerve pursues a separate course; they do not form plexuses as do the cervical, lumbar, and sacral nerves.

The intercostal nerves are distributed chiefly to the parietes of thorax and abdomen; the first two thoracic nerves also give branches to the brachial plexus which are carried into the upper extremities; the next four are confined to the walls of the thorax; the next five supply the walls of thorax and abdomen; the twelfth is distributed to the abdominal wall and the skin of the buttock.

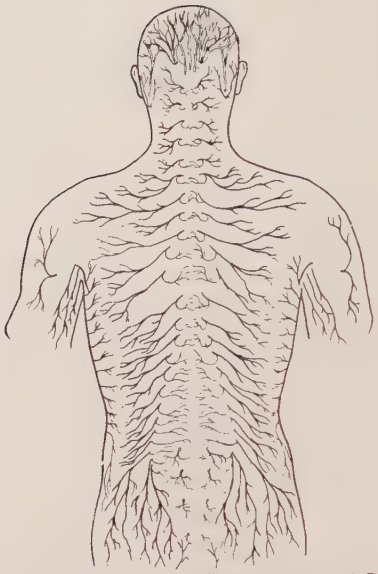

Fig. 60. Schema of Superficial Nerves of Back.

The anterior primary division of the **first thoracic nerve** is divided into two branches; the larger branch leaves the nerve in front of the neck of the first rib and enters into the formation of the brachial plexus; it is frequently joined by a smaller branch from the second thoracic. The smaller branch of the first thoracic becomes the **first intercostal nerve,** runs around in the first intercostal space, and ends as the **first anterior cutaneous branch** on the anterior aspect of the thorax. As a rule, the first intercostal does not give off a lateral cutaneous branch as do the nerves below it, but it sometimes gives a branch to the intercostobrachial.

The anterior divisions of the second, third, fourth, fifth, and sixth thoracic nerves, and the small branch of the first thoracic are the **thoracic intercostal nerves** because they are confined to the thorax. They occupy the intercostal spaces below the intercostal vessels. At the back, they are placed between the pleura and the posterior intercostal membranes; they then penetrate the membrane and run as far as the middle of the rib between the external and internal intercostal muscles. Then they enter the substance of the intercostales interni and occupy that position as far as the costal cartilage. At the cartilage, they move to the inner surface of the muscles and are placed between them and the pleura. Near the edge of the sternum, they turn abruptly outward, penetrating in turn the internal interossei, the anterior intercostal membrane, and the pectoralis major muscle, and are distributed to the skin of the front of the thorax and over the mamma. In their course the

thoracic intercostals give off small branches to the intercostales, the subcostales, the levatores costarum, the serratus posticus superior, and the transversus thoracic.

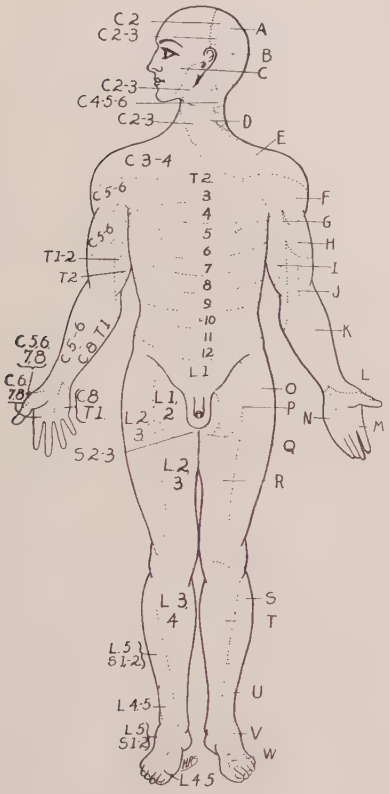

Fig. 61. Areas of Cutaneous Sensory Nerve Distribution (Ventral). A, Greater Occipital n.; B, Lesser Occipital n.; C, Trigeminal n.; D, Cervical Cutaneous; E, Supraclavicular, Sternal, and Acromial nn.; F, Axillary n.; G, Medial Cutaneous n. of Arm; H, Dorsal Cutaneous n. of Arm; I, Intercosto-Brachial n.; J, Medial Cutaneous n. of Forearm; K, Musculocutaneous n.; L, Radial n.; M, Median n.; N, Ulnar n.; O, Lateral Cutaneous n. of Thigh; P, Genito-Femoral n.; Q, Ilioinguinal and Dorsal Cutaneous; R, Medial Cutaneous n.; S, Common Peroneal n.; T, Saphenous n.; U, Superficial Peroneal n.; V, Sural n.; W, Deep Peroneal n.

Each intercostal nerve gives off a **lateral cutaneous branch,** about halfway between the vertebrae and sternum. These pierce the external intercostals and the serratus anterior and divide into anterior and posterior branches. The **anterior** branches run forward to the side and front of the chest and supply the skin and mamma; those of the fifth and sixth thoracic carry motor fibres to the upper portion of the obliquus externus abdominis. The **posterior** branches run backward to the skin over the scapulae and latissimus dorsi.

The lateral cutaneous branch of the second intercostal nerve does not divide into anterior and posterior branches; it is named the intercostobrachial nerve. It penetrates the external intercostal muscle and the serratus anterior, crosses the axilla to the medial side of the arm, and unites with a branch from the medial brachial

cutaneous nerve. It then passes through the fascia and is distributed to the skin of the medial and posterior aspect of the upper half of the arm. It communicates with the posterior brachial cutaneous branch of the radial nerve. The size of this nerve and of the medial brachial cutaneous nerve is in inverse proportion.

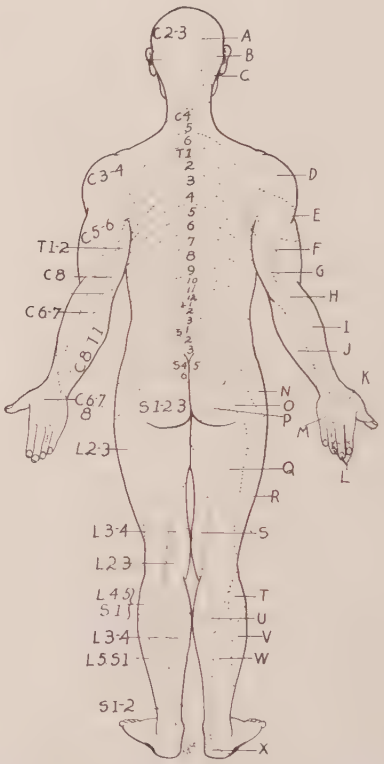

Fig. 62. Areas of Cutaneous Sensory Nerve Distribution (Dorsal).
A, Lesser Occipital n.; B, Greater Occipital n.; C, Auricular n.; D, Supra-Clavicular n.; E, Axillary n.; F, Intercosto-Brachial n.; G, Medial Brachial Cutaneous n.; H, Dorsal Cutaneous n. of Forearm; I, Lateral Cutaneous Nerve of Forearm; J, Medial Cutaneous n. of Forearm; K, Radial n.; L, Median n.; M, Ulnar n.; N, Iliohypogastric n.; O, Dorsal Divisions of L. 1, 2, 3 n.; P, Dorsal Divisions of S. 1, 2, 3; Q, Dorsal Femoral Cutaneous; R, Lateral Femoral Cutaneous; S, Anterior Femoral Cutaneous n.; T, Common Peroneal n.; U, Saphenous n.; V, Superficial Peroneal n.; W, Sural n.; X, Tibial n.

Thoracico-abdominal Intercostal Nerves. This name is applied to the anterior divisions of the seventh, eighth, ninth, tenth, and eleventh thoracic nerves because, after running as intercostal nerves between the ribs, they debouch upon the anterior abdominal wall to supply its muscles and integument. Each has a downward slant corresponding at the ends of the ribs with the downward slant of the ribs, and continuing the downward direction upon the abdominal wall; hence, the area of distribution of each nerve is somewhat lower than the level of its spinal origin. At the anterior end of the costal spaces, they pass behind the costal cartilages, and between the obliquus internus and transversus abdominis, and penetrate the sheath of the rectus abdominis.

About the middle of its course, each thoracicoabdominal intercostal nerve gives off a **lateral cutaneous branch,** which penetrates

the external intercostal muscles and external abdominal oblique muscle, and divides into anterior and posterior cutaneous branches, to supply the skin of the abdomen and back, very much as the branches of the upper thoracic nerves are distributed. Each lower intercostal also gives branches to the intercostales and abdominal muscles, as far forward as the edge of the rectus abdominis. It then terminates in an **anterior cutaneous nerve** of the abdomen, which supplies the skin of the front of the abdomen near the mid-line.

The anterior division of the **twelfth thoracic** differs from the others; it is larger and pursues a different course. It communicates with the first lumbar nerve and with the iliohypogastric branch of the lumbar plexus. Its **lateral cutaneous branch** is large and does not divide into anterior and posterior divisions; it pierces the internal and external oblique muscles and descends over the iliac crest in front of the lateral cutaneous branch of the iliohypogastric, and is distributed to the skin of the anterior part of the gluteal region, as far down as the greater trochanter.

The Lumbosacral Plexus.

The anterior primary divisions of the lumbar, sacral, and coccygeal nerves, with a branch from the twelfth thoracic which frequently joins the first lumbar, mingle in a plexiform arrangement called the lumbosacral plexus, from which branches are distributed to the muscles and integument of the lower extremities. The lumbosacral plexus is divided into three parts—the **lumbar, sacral,** and **pudendal plexuses.**

The anterior divisions of the **lumbar nerves** grow larger from above downward. They receive gray rami communicantes, near their origin, from the adjacent ganglia of the sympathetic trunk. The first and second, and sometimes the third, lumbar nerves give off white rami communicantes to the sympathetic. The nerves slant outward behind the psoas major, or between its fasciculi, giving branches to that muscle and to the quadratus lumborum. Here the first three and a part of the fourth are united for the formation of the **lumbar plexus.** The lesser part of the fourth and the whole of the fifth unite to form the **lumbosacral trunk** (*lumbosacral cord*), which crosses the brim of the pelvis and enters into the formation of the sacral plexus. The fourth nerve, thus divided, is called **nervus furcalis.**

The **Lumbar Plexus** is placed in front of the transverse processes of the lumbar vertebrae and in the back part of the psoas

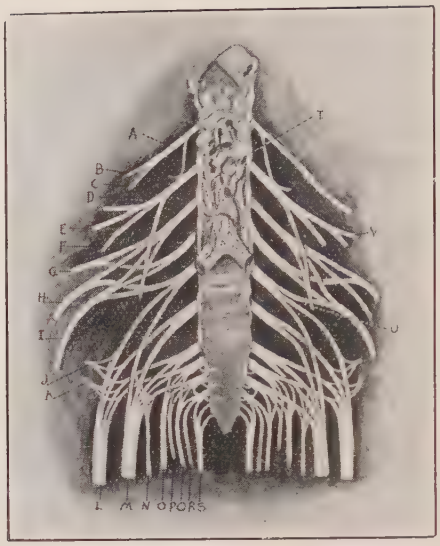

Fig. 63.
A, T. 12; B, Iliac Branch; C, Anterior Branch; D, Iliohypogastric n.; E, Hypogastric Branch; F, Ilioinguinal n.; G, Lateral Cutaneous n. of Thigh; H, Femoral Nerve; I, Obturator n.; J, Superior Gluteal n.; K, Inferior Gluteal n.; L, Peroneal n.; M, Tibial n.; N, Nerve to Hamstring Muscles; O, Dorsal Cutaneous n. of Thigh; P, Perforating Branch; Q, Pudendal n.; R, Perenal n.; S, Ano-Coccygeal n.; T, Sympathetic Plexus; U, Genitofemoral n.; V, Iliac Branch of Iliohypogastric.

major muscle. It is made up of the anterior divisions of the first three lumbar nerves and a part of the fourth, with a branch from the twelfth thoracic. These nerves divide simply, and the divisions of one unite with those of the adjacent nerves.

The exact mode of division and reunion is not always the same, but whatever the distribution and rearrangement of fibres in the plexus, each of the branches of distribution to the periphery derives its fibres from practically the same spinal nerves in all subjects. Generally, the first lumbar nerve is joined by a branch from the twelfth thoracic and then splits into an upper and a lower branch; the upper and larger branch divides into the iliohypogastric and ilioinguinal nerves; the lower branch joins with a branch from the second lumbar to form the genitofemoral nerve. The remaining part of the second nerve, and the third and fourth nerves, divide into ventral and dorsal divisions. The ventral divisions of the second, third, and fourth nerves unite to form the obturator nerve. The dorsal divisions of the second and third nerves split into two branches; the smaller branches of each come together to form the lateral femoral cutaneous nerve; the larger branches of each join with the dorsal division of the fourth nerve to make up the femoral nerve. When there is an accessory obturator, it arises by two small branches from the third and fourth nerves.

The **Iliohypogastric nerve** derives its fibres from L1, passes the psoas major and slants in front of the quadratus lumborum to the iliac crest. It then penetrates the back part of the transversus abdominis and divides into an **anterior** and a **lateral cutaneous branch.** The lateral branch pierces the muscles above the iliac crest and supplies the skin of the gluteal region behind the cutaneous distribution of the twelfth thoracic. The anterior cutaneous branch extends onward between the obliquus internus and transversus, then penetrates the obliquus externus about an inch above the external inguinal ring, and supplies the skin of the hypogastric region. The iliohypogastric nerve communicates with the last thoracic and ilioinguinal nerves.

The **Ilioinguinal nerve** arises with the iliohypogastric from L1. It passes the psoas major and quadratus lumborum just below the iliohypogastric, pierces the obliquus internus, to which it gives filaments, and accompanies the spermatic cord through the external inguinal ring, to be distributed to the skin over the upper and medial part of the thigh, to the skin over the root of the penis and upper part of the scrotum in the male, and to the skin covering the mons pubis and labium majus in the female.

The **genitofemoral nerve** arises from L1 and L2. It passes obliquely through the psoas major and emerges from its medial border opposite the fibrocartilage between the third and fourth lumbar vertebrae; it then descends, under cover of the peritoneum, on the ventral surface of the psoas major and divides into the external spermatic and lumboinguinal nerves. The first (*genital branch*) descends behind the spermatic cord to the scrotum, supplies the cremaster muscle, and gives a few filaments to the skin of the scrotum; in the female, it accompanies the round ligament of the uterus. The second, or lumboinguinal branch (*crural or femoral branch*), descends on the external iliac artery, passes beneath the inguinal ligament, and enters the sheath of the femoral vessels.

The **lateral femoral cutaneous nerve** (*external cutaneous nerve*) arises from the dorsal divisions of L2 and L3. It passes the psoas major about its middle and crosses the iliacus toward the anterior superior iliac spine, then crosses the inguinal ligament, and passes over the sartorius muscle into the thigh, where it divides into an **anterior** and a **posterior** branch. The anterior branch approaches the surface of the thigh about four inches below the inguinal ligament and divides into branches which extend to the

skin of the front and lateral aspect of the thigh, down to the knee. Some branches enter into the patellar plexus. The posterior branch penetrates the fascia lata and divides into branches which pass backward to supply the skin of the posterior and lateral surfaces of the thigh from the level of the greater trochanter down to the middle of the thigh.

The **obturator nerve** is the union of the ventral divisions of L1, L2, L3, and L4; the branch from the third is the largest. It descends through the substance of the psoas major and leaves its medial margin near the brim of the pelvis, passes behind the common iliac vessels, and runs along the lateral wall of the pelvis to the obturator foramen. It passes through the obturator foramen into the thigh and splits into an anterior and a posterior branch.

The **anterior branch** descends in front of the adductor brevis and behind the pectineus and adductor longus; at the lower border of the latter it communicates with the anterior cutaneous and saphenous branches of the femoral nerve, to form a plexus. It then follows the femoral artery, to which its terminal branches are given. An articular branch to the hip-joint is given off near the obturator foramen. Behind the pectineus, branches are given off to the adductor longus and gracilis, usually to the adductor brevis, and occasionally to the pectineus. Sometimes, instead of forming a plexus with branches of the femoral, a cutaneous nerve is continued from the obturator into the leg, in which case it supplies the skin of the tibial side as far as the middle of the leg.

The **posterior branch** penetrates the anterior part of the obturator externus muscle and supplies it, then passes behind the adductor brevis on the front of the adductor magnus, where it divides into muscular branches to the adductor magnus and adductor brevis, and a filament to the knee-joint. This latter is not always present.

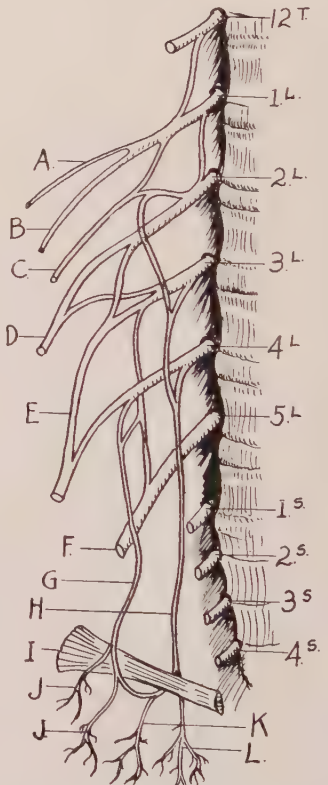

Fig. 64. Schema of Obturator Nerve.

A, Iliohypogastric n.; B, Ilioinguinal n.; C, Genito-Femoral n.; D, Lateral Femoral Cutaneous n.; E, Femoral n.; F, Lumbosacral Trunk; G, Accessory Obturator; H, Obturator n.; I, Obturator Muscle; J, To Pectineous Muscle; K, To Adductor Brevis; L, To Adductor Longus.

The **accessory obturator nerve** is present in only about 29 per cent of all cases; when absent, its fibres seem to be carried chiefly in the obturator nerve, from which the hip-joint then receives two filaments instead of one. It arises from the ventral divisions of L3, and L4, descends along the medial border of the psoas major, crosses the superior ramus of the pubis, and passes under the pectineus, where it divides into numerous branches. One supplies the pectineus, another the hip-joint, and another communicates with the anterior branch of the obturator nerve.

The **femoral nerve** arises from the dorsal divisions of L2, L3, and L4. It is the largest branch of the lumbar plexus. It descends through the psoas major to emerge at its lower lateral border, passes behind the iliac fascia, runs beneath the inguinal ligament into the thigh, and divides into an anterior and a posterior division. Within the abdomen the femoral nerve gives branches to the iliacus and to the femoral artery. Most of its branches are given off in the thigh. Here the anterior division gives origin to anterior cutaneous and muscular branches. The anterior cutaneous branches are the intermediate and medial cutaneous nerves. The **intermediate cutaneous nerve** becomes superficial about 3 inches below the inguinal ligament and divides into two branches which supply the skin of the front of the thigh as low as the knee. They join with the medial cutaneous nerve and the infrapatellar branch of the saphenous, to form the **patellar plexus.** The **medial cutaneous nerve** divides in front of the femoral artery into an anterior and a posterior branch. The **anterior branch** descends on the sartorius, pierces the fascia lata at the lower third of the thigh and divides into two branches; the one supplies the skin down to the medial side of the knee; the other crosses to the lateral side of the patella. The **posterior branch** follows the medial border of the sartorius to the knee, pierces the fascia lata, communicates with the saphenous nerve, and gives off some cutaneous branches. It terminates by supplying the skin of the medial side of the leg.

The **muscular branches** of the femoral nerve supply the pectineus, sartorius, and the four parts of the quadriceps femoris. The nerve to the pectineus is given off immediately below the inguinal ligament; that to the sartorius arises in common with the intermediate cutaneous. The branches to the quadriceps femoris are given off from the posterior division of the femoral nerve. One

passes to the rectus femoris; a large branch reaches the vastus lateralis; the branch to the vastus medialis descends in company with the saphenous nerve lateral to the femoral vessels; there are two or three branches to the vastus intermedius.

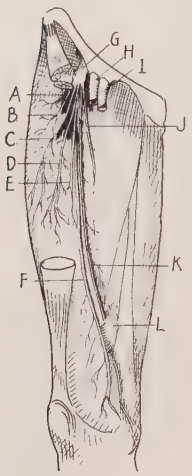

Fig. 65.
Diagram of Femoral Nerve.
A, Nerve to Rectus Femoris Muscle; B, C, Nerve to Vastus Lateralis; D, E, F, Nerves to Vastus Medialis; G, Femoral Nerve; H, Femoral Artery; I, Femoral Vein; J, Medial Cutaneous Nerve of Thigt; K, Saphenous n.; L, Adductor Canal.

From the branch to the rectus femoris a filament passes to the hip-joint. From the nerve to the vastus lateralis, a branch goes to the knee-joint; another from the nerve to the vastus medialis; and a third from the nerve to the vastus intermedius.

The **saphenous nerve** is the longest cutaneous branch of the femoral nerve. It arises from the posterior division. It approaches the femoral artery and runs with it is far as the lower part of the adductor magnus; it then leaves the artery and descends along the medial side of the knee, pierces the fascia between the tendons of the sartorius and gracilis, and becomes subcutaneous. It then descends along the tibial side of the leg and at the lower third of the leg splits into two branches; one ends at the ankle and the other passes in front of the ankle and supplies the skin of the medial side of the foot as far as the ball of the great toe, communicating with the medial branch of the superficial peroneal nerve. The saphenous nerve gives off, in the middle of the thigh, a branch to the subarterial plexus; at the medial side of the knee it gives off a large infrapatellar branch to the skin in front of the patella. It gives several branches to the patellar plexus; and below the knee it supplies the skin of the front and medial side of the leg.

The Sacral and Coccygeal Nerves.

The anterior divisions of these nerves form the sacral and pudendal plexuses, the sacral nerves being joined by the lumbosacral trunk. The anterior divisions of the upper four sacral nerves emerge from the vertebral canal through the anterior sacral foramina, the fifth between sacrum and coccyx, and the coccygeal below the first piece of the coccyx. The two upper sacral nerves are largest; they then decrease in size from above downward. Each

sacral nerve receives a gray ramus communicans from the adjacent sympathetic ganglion, and the third, and sometimes the second and fourth, give white rami to the sympathetic.

The Sacral Plexus.

In the formation of this plexus, the lumbosacral trunk is formed by the union of a branch from the fourth lumbar nerve with the entire anterior division of the fifth. The trunk emerges from the medial border of the psoas major muscle and descends over the pelvic brim to join the anterior division of the first sacral nerve. This, together with the anterior division of the second sacral nerve and a part of the anterior division of the third, makes up the sacral plexus. Part of the anterior division of the third sacral enters into the formation of the pudendal plexus.

The nerves above mentioned converge toward the lower part of the greater sciatic foramen, and there unite to form a large, flattened band. Several anterior and posterior branches are given off by this band and the band itself continues as the **sciatic nerve.**

All the nerves entering the sacral plexus divide into ventral and dorsal divisions, excepting the third sacral. The branches which arise entirely from the ventral divisions are: (a) the nerve to the quadratus femoris and gemellus inferior, and (b) the nerve to the obturator internus and gemellus superior. The branches which originate entirely in the posterior divisions are: (a) the nerve to the piriformis; (b) the superior gluteal nerve; and (c) the inferior gluteal nerve. The posterior femoral cutaneous nerve and the sciatic nerve arise from both the ventral and dorsal divisions.

The **Nerve to the Quadratus Femoris and Gemellus Inferior** arises from the ventral divisions of L4, L5, and S1, leaves the pelvis through the greater sciatic foramen, and runs downward in front of the sciatic nerve, the gemelli, and the tendons of the obturator internus. It sends an articular branch to the hip-joint and enters the anterior surface of the muscles for which it is named.

The **Nerve to the Obturator Internus and Gemellus Superior** leaves the ventral divisions of L5, S1, and S2. It passes through the greater sciatic foramen below the piriformis, gives a branch to the gemellus superior, then crosses the ischial spine, re-enters

the pelvis through the lesser sciatic foramen, and penetrates the pelvic surface of the obturator internus.

The **Nerve to the Piriformis** arises from the dorsal divisions of S1 and S2, or from S2 alone. It enters the anterior surface of the piriformis. Sometimes it is a double nerve.

The **Superior Gluteal Nerve** arises from the dorsal divisions of L4, L5, and S1; leaves the pelvis through the greater sciatic foramen above the piriformis, and divides into a superior and an inferior branch. The **superior** branch follows the upper branch of the deep division of the superior gluteal artery, to terminate in the gluteus maximus muscle. The **inferior** branch follows the lower branch of the deep division of the superior gluteal artery across the gluteus minimus and gives branches to the glutei medius and minimus. It ends in the fascia lata.

The **Inferior Gluteal Nerve** arises from the dorsal divisions of L5, S1, and S2, leaves the pelvis through the greater sciatic foramen below the piriformis, and splits into branches which enter the deep surface of the gluteus maximus.

The **Posterior Femoral Cutaneous Nerve** (*small sciatic nerve*) arises both from the dorsal divisions of S1 and S2, and from the ventral divisions of S2 and S3, and is distributed to the skin of the perineum and posterior surface of the thigh and leg. It leaves the pelvis through the greater sciatic foramen below the piriformis, descends beneath the gluteus maximus with the inferior gluteal artery, and runs down the back of the thigh beneath the fascia lata, and over the long head of the biceps femoris to the back of the knee. It then pierces the deep fascia and follows the small saphenous vein to about the middle of the back of the leg, communicating with the sural nerve. Its branches are all cutaneous. They are:

(a) Three or four **gluteal branches,** which run upward along the lower border of the gluteus maximus to supply the skin over the lower and lateral part of that muscle;

(b) The perineal branches to the skin of the upper and medial part of the thigh. One branch, the **inferior pudendal,** curves forward below and in front of the ischial tuberosity and runs forward in the perineum, beneath the superficial fascia, to the skin of the

scrotum in the male, or of the labium majus in the female. It communicates with the posterior scrotal and inferior hemorrhoidal nerves.

(c) The **branches to the back of the thigh and leg** are numerous filaments from both sides of the nerve, and supply the skin of the back and medial side of the thigh, the popliteal fossa, and the upper part of the back of the leg.

The **Sciatic Nerve** is in reality a direct continuation of the major portion of the sacral plexus. It is the largest and longest nerve in the body, measuring about eight-tenths of an inch in diameter, and often extending more than a yard in length. Its spinal origin is by way of the anterior divisions of L4, L5, S1, S2, and S3, and the posterior divisions of all of these except the lowest. It is a tough, well-protected nerve, by virtue of the strength and density of its connective tissue sheaths. It is a mixed nerve, supplying almost all of the skin of the leg and the muscles of the back of the thigh and those of the leg and foot.

The sciatic nerve emerges from the pelvis by the greater sciatic foramen, below the piriformis muscle. The uniting divisions of the sacral plexus usually form a single trunk which passes down to the back of the thigh and divides into two great nerves, the **tibial** and **common peroneal.** These may arise separately from the plexus and pass as two nerves through the sciatic foramen, but they usually run together to about the junction of the upper and middle thirds of the thigh; their point of divergence is not constant. Even though they lie together for a distance, they are, in effect, two nerves.

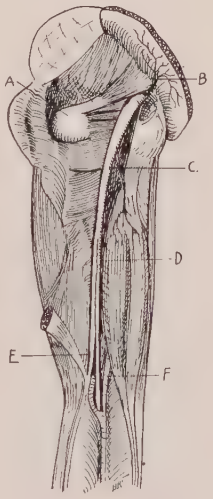

Fig. 66.
Diagram of Sciatic Nerve.
A, Greater Trochanter; B, Inferior Gluteal n.; C, Sciatic n.; D, Tibial n.; E, Peroneal n.; F, Vein.

Before dividing (*usually*) the sciatic gives off articular branches to the hip-joint, and muscular branches to the biceps femoris, semitendinosus, semimembranosus, and adductor magnus. That to the short head of the biceps femoris arises from the common peroneal portion of the sciatic trunk, while the remaining muscular branches arise from the tibial portion.

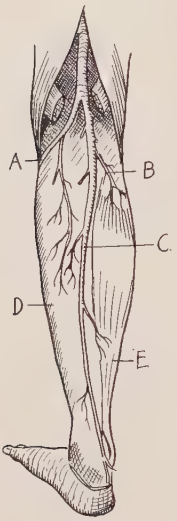

Fig. 67.
Tibial Nerve.
A, Common Peroneal Nerve; B, Medial Sural Nerve; C, Tibial Nerve; D, Flexor Hallucis Longus Muscle; E, Flexor Digitorum Longus.

The **Tibial Nerve** (*internal popliteal nerve*) is the larger of the two divisions of the sciatic. It arises from the anterior divisions of L4, L5, and S1, S2, and S3. It passes down the back of the thigh and through the middle of the popliteal fossa to the lower border of the popliteus muscle, and beneath the arch of the soleus; then descends the back of the leg with the posterior tibial vessels to a point between the medial malleolus and the heel. Here it divides into the medial and lateral plantar nerves. It lies deep in the thigh and then more superficial at the knee; in the leg it is covered by the muscles of the calf, and lower down by the skin and superficial fascia. The branches of the tibial nerve are: (1) **articular**; (2) **muscular**; (3) **medial sural cutaneous**; (4) **medial calcaneal**; (5) **medial plantar**; and (6) **lateral plantar.**

(1) Three **articular branches** are usually given to the knee-joint. A branch is given off the ankle-joint just above the division of the tibial into the two plantar nerves.

(2) There are four or five **muscular branches** which leave the nerve between the two heads of the gastrocnemius muscle; they are distributed to that muscle and to the plantaris, soleus, and popliteus. Lower down, other branches arise either separately or by a single trunk and are distributed to the soleus, tibialis posterior, flexor digitorum longus, and flexor hallucis longus.

(3) The **medial sural cutaneous nerve** passes down between the two heads of the gastrocnemius and, at the middle of the back of the leg, penetrates the deep fascia and joins with the anastamotic branch of the common peroneal to form the sural nerve. The **sural nerve** (*short sophenous nerve*) descends lateral to the tendo calcaneus, between the lateral malleolus and the calcaneus, then runs forward below the lateral malleolus and then along the lateral side of the foot and little toe as the **lateral dorsal cutaneous nerve.** On the dorsum of the foot it communicates with the intermediate dorsal cutaneous nerve and in the leg its branches mingle with those of the posterior femoral cutaneous.

(4) The **medial calcaneal branches** supply the skin of the heel and of the medial side of the sole of the foot.

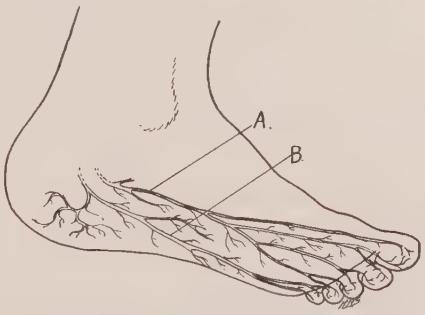

Fig. 68. Plantar Nerve Distribution. A, Medial Plantar Nerve; B, Lateral Plantar Nerve.

(5) The **medial plantar nerve** is the larger of the two terminal divisions of the tibial nerve; it follows the medial plantar artery. Originating under the laciniate ligament, it passes under the adductor hallucis, and beyond this muscle, gives off a proper digital plantar nerve and, opposite the bases of the metatarsal bones, divides into three common digital plantar nerves. The branches of the medial plantar nerve are: (1) **cutaneous**; (2) **muscular**; (3) **articular**; (4) a **proper digital nerve** to the medial side of the great toe; and (5) three **common digital nerves.**

(1) The **cutaneous branches** are distributed to the skin of the sole of the foot.

(2) The **muscular branches** supply the abductor hallucis, flexor digitorum brevis, flexor hallucis brevis, and the first lumbricalis.

(3) The **articular branches** are distributed to the articulations of the tarsus and metatarsus.

(4) The **proper digital nerve of the great toe** supplies the flexor hallucis brevis and the skin on the medial side of the great toe.

(5) Each of the three **common digital branches** passes between the divisions of the plantar aponeurosis and splits into two proper digital branches. Those of the first common digital nerve supply the adjoining sides of the great and second toes; those of the second, the adjoining sides of the second and third toes; those of the third, the adjacent sides of the third and fourth toes. Each proper digital branch gives off cutaneous and articular filaments, and each sends a dorsal branch upward opposite the last phalanx, to the structures around the nail and to the ball of the toe. These nerves are analagous in their distribution to digital branches of the median nerve.

The **Lateral Plantar Nerve** has a distribution similar to that of the ulnar nerve in the hand; it supplies the skin of the fifth toe and the lateral half of the fourth, and most of the deep muscles. It follows the lateral plantar artery to the lateral side of the foot and, in the interval between the flexor digitorum brevis and the

quadratus plantae, splits into a superficial and a deep branch. Before dividing, it supplies the quadratus plantae and abductor digiti quinti. The **superficial branch** splits into a proper and a common digital nerve; the proper digital nerve supplies the two interossei muscles of the fourth intermetatarsal space, the flexor digiti quintus brevis, and the skin of the lateral side of the small toe; the common digital nerve splits into two proper digital nerves which supply the adjacent sides of the fourth and fifth toes. The **deep branch** follows the lateral plantar artery on the deep surface of the tendons of the flexor muscles and the adductor hallucis, and supplies all the interossei muscles except those in the fourth intermetatarsal space, the second, third, and fourth lumbricales, and the adductor hallucis.

The **Common Peroneal Nerve** (*external popliteal nerve*) is derived from the dorsal divisions of L4, L5, S1, and S2. It is about one-half the size of the tibial nerve. From the bifurcation of the sciatic, it passes obliquely downward on the lateral side of the popliteal fossa to the head of the fibula. It lies between the tendons of the biceps femoris muscle and lateral head of the gastrocnemius, winds around the neck of the fibula, and divides beneath the peroneus longus muscle into the superficial and deep peroneal nerves. Before dividing it gives off articular and lateral sural cutaneous nerves.

There are three **articular branches** to the knee-joint; two follow the superior and inferior lateral genicular arteries to the knee; the third (*recurrent*) leaves the common peroneal nerve at its division and ascends to the front of the knee with the anterior recurrent tibial artery.

The **lateral sural cutaneous nerve** supplies the skin of the posterior and lateral surfaces of the leg; one of its branches, the **peroneal anastamotic**, arises near the head of the fibula, crosses the lateral head of the gastrocnemius and, near the middle of the leg, unites with the medial sural cutaneous to form the sural nerve.

The **Deep Peroneal Nerve** (*anterior tibial nerve*) begins between the fibula and the upper part of the peroneus longus muscle, at the bifurcation of the common peroneal nerve. It passes obliquely forward beneath the extensor digitorum longus to the front of the interosseous membrane; it descends with the anterior tibial artery from about the middle of the leg to the front of the ankle-joint, and divides into a lateral and a medial terminal branch. In the leg the deep peroneal nerve gives **muscular branches** to the tibialis anterior,

extensor digitorum longus, peroneus tertius, and extensor hallucis proprius, and an **articular branch** to the ankle-joint.

The **lateral terminal branch** passes across the tarsus and supplies the extensor digitorum brevis; three small **interosseous branches** pass to the tarsal joints and the metatarsophalangeal joints of the second, third, and fourth toes. The **medial terminal branch** passes along the dorsum of the foot, and, at the first interosseous space, divides into two **dorsal** digital branches, which are distributed to the adjoining sides of the great and second toes, communicating with the medial dorsal cutaneous branch of the superficial peroneal nerve. A filament is given off before the division, to supply the metatarso-phalangeal joint of the great toe and the first dorsal interosseous muscle.

Fig. 69.
Peroneal Nerve.
A, Saphenous n.; B, Common Peroneal n.; C, Superficial Peroneal n.; D, Deep Peroneal n.; E, Annular Ligament; F, Sural n.

The **Superficial Peroneal Nerve** passes between the peronei and the extensor digitorum longus, penetrates the deep fascia in the lower third of the leg and divides into the medial and intermediate dorsal cutaneous nerves. Before dividing it gives off muscular branches to the peronei longus and brevis, and cutaneous branches to the skin of the lower part of the leg. The **medial dorsal cutaneous branch** descends in front of the ankle-joint and divides into two dorsal digital branches, one to the medial side of the great toe and the other to adjacent sides of the second and third toes. It also supplies the skin of the medial side of the foot and ankle and communicates with the saphenous and deep peroneal nerves. The **intermediate dorsal cutaneous branch** passes along the lateral side of the dorsum of the foot and splits into **dorsal digital branches,** to the adjacent sides of the third and fourth, and of the fourth and fifth, toes. It supplies the integument of the lateral side of the foot and ankle and communicates with the sural nerve.

The Pudendal Plexus.

The pudendal plexus is situated on the posterior wall of the pelvis and is usually formed by branches from the anterior divisions of S2 and S3, and by the whole of the anterior divisions of S4 and S5, and the coccygeal nerve. Since some of the branches of this plexus frequently arise in conjunction with branches of the

sacral plexus, it follows that the pudendal plexus is not clearly set off from the sacral. Indeed, these two, together with the lumbar plexus which is connected with the sacral plexus by the lumbosacral trunk, are commonly described as one great plexus, the lumbosacral. The pudendal plexus gives off **perforating cutaneous, pudendal, visceral, muscular,** and **anococcygeal branches.**

The **perforating cutaneous nerve** arises from the posterior surface of S2 and S3, penetrates the lower part of the sacrotuberous ligament, winds around the lower border of the gluteus maximus, and supplies the integument over the medial and lower parts of that muscle. It may be absent, in which case its area is innervated by a branch from the posterior femoral cutaneous, or a branch direct from some of the lower sacral nerves.

The **pudendal nerve** (*internal pudic nerve*) originates from the ventral branches of S2, S3, and S4, passes between the piriformis and coccygeus muscles, and leaves the pelvis by the lower part of the greater sciatic foramen. It then crosses the spine of the ischium and re-enters the pelvis through the lesser sciatic foramen. It passes upward and forward along the lateral wall of the ischiorectal fossa, in company with the internal pudendal vessels in a sheath of fascia called **Alcock's canal,** gives off the **inferior hemorrhoidal nerve,** and then divides into the **perineal nerve** and the **dorsal nerve of the penis** or **clitoris.** The **inferior hemorrhoidal nerve** supplies the sphincter ani externus and the integument around the anus. The **perineal nerve** is the larger and lower of the two terminal branches; it accompanies the perineal artery and divides into posterior scrotal (*or labial*) and muscular branches. The posterior scrotal, or labial, branches are two, medial and lateral. They pierce the urogenital diaphragm and run forward in company with the posterior scrotal branches of the perineal artery. They supply the skin of the scrotum in the male and of the labium majus in the female, and communicate with the perineal branch of the posterior femoral cutaneous nerve. The muscular branches of the perineal nerve are distributed to the transversus perinei superficialis, bulbocavernosus, ischiocavernosus, and constrictor urethrae. A branch, the **nerve to the bulb,** pierces the bulbocavernosus, and supplies the corpus cavernosum urethrae, ending in the urethral mucous membrane.

The **dorsal nerve of the penis** is the deepest division of the pudendal nerve. It follows the internal pudendal artery along the ramus of the ischium, then runs forward between the superior and

inferior layers of fascia of the urogenital diaphragm. It penetrates the inferior layer, gives a branch to the corpus cavernosum penis, and passes forward with the dorsal artery of the penis upon the dorsum of that organ, and terminates in the glans penis. There is a very small, but otherwise analagous, nerve in the female to supply the clitoris.

The **visceral branches** arise from S3, S4, and sometimes S2. They carry fibres analagous to the white rami communicantes given off to the sympathetic trunk in the thoracolumbar region, but these fibres usually pass the sympathetic trunk in the sacral region, and terminate in relation to more peripherally placed ganglia, in close relation to the organs to which their postganglionic fibres are to be distributed. These organs are the bladder and rectum, and, in the female, the vagina. The visceral branches from the pudendal plexus communicate freely with the pelvis plexuses of the sympathetic.

Muscular branches from S4 supply the levator ani, coccygeus, and sphincter ani externus.

Anococcygeal nerves arise from the **coccygeal plexus,** formed by the union of the fifth sacral nerve with a small branch of the fourth and with the coccygeal nerve. They supply the skin around the coccyx.

THE SYMPATHETIC NERVE SYSTEM

That portion of the peripheral nerve system which innervates all the glands of the body, all the non-striated muscle tissue, and the striated muscle of the heart, is commonly called the **sympathetic system.** It has been called the **vegetative system** because it controls those organs and tissues concerned with the processes of living rather than with relation of the being to his environment. By others it has been termed the **autonomic system** because of the belief that its action is largely independent of the cerebrospinal system. Of all the names suggested, "sympathetic system" is most widely used, although not justified by the ancient belief in "sympathy" which prompted it, and will be employed herein as a general title to designate all the nerve organs outside the cerebrospinal system.

The sympathetic system is connected with the cerebrospinal system by groups of **preganglionic fibres** which emerge from the central system with various cranial and spinal nerves and terminate in sympathetic ganglia; from these ganglia arise **postganglionic fibres** which convey nerve stimuli to the blood-vessels, glands, and vital organs. The former are medullated fibres originating in the central system; the latter are non-medullated and are the processes of cells in the sympathetic ganglia. Most of these fibres, both preganglionic and postganglionic, are efferent, but there are also afferent fibres which pass from the viscera to the ganglia and others which pass from the ganglia to the central system.

GENERAL ARRANGEMENT OF SYMPATHETIC

Unlike the cerebrospinal system, in which the ganglionic masses are arranged in an elongated central core, the sympathetic presents many ganglia which are separated from each other except for communicating nerve cords; many of these lie in close juxtaposition with the viscera which they innervate. The sympathetic is the oldest portion of the nerve system and in primitive animal species is developed, and remains, in intimate relation with the internal organs. The cerebrospinal system must be regarded as a newer growth of nerve organs to establish the functions of somatic sensation and motion, and of consciousness, with which are grouped a multitude of associative neurons which serve to coordinate the variety of impressions arising from a more extended and complex

periphery and to translate them into appropriate actions. These associative neurons, together with the cells belonging to the somatic neurons, have withdrawn from the vital organs and their related sympathetic nerves to a common central situation from which they continue to exercise a supervisory control over the peripheral nervous elements. There is, in reality, only **one** nerve system, of which the sympathetic is that part directly and specially concerned with the maintenance of life. This system retains an intimate connection with the central system, which connection will be described below.

The sympathetic system consists of: (1) the **sympathetic trunks,** a double chain of ganglia close to the vertebral column, in which the ganglia are connected to each other by nerve cords; (2) three great **prevertebral plexuses,** situated in the thoracic, abdominal, and pelvic cavities respectively and each giving off subplexuses; (3) many **collateral ganglia,** placed in close relation to the organs they supply; (4) the **connecting sympathetic nerves** which unite the sympathetic cords, the prevertebral plexuses, and the collateral ganglia; and (5) the **terminal branches,** which complete the pathway to heart, glands, and non-striated muscle. The fibres of the terminal branches may arise in the cells of the nearest ganglion, or may come from one more remote and penetrate the collateral ganglion. (6) Certain cranial nerves carry fibres known as sympathetic, which terminate in sympathetic ganglia, and (7) the second, third, and fourth sacral nerves give off similar fibres commonly called the **sacral sympathetic.**

(1) The **Sympathetic Trunks** (*gangliated cord*) extend from the base of the skull to the coccyx, in close relation with the vertebral column. There are 23 or 24 ganglia in each trunk; in the neck they lie in front of the transverse processes of the cervical vertebrae; in the thorax, in front of the heads of the ribs; in the lumbar region, on the sides of the bodies of the vertebrae; and in the sacral region, in front of the sacrum. There are 3 Cervical ganglia in each trunk, 12 Thoracic, 4 Lumbar, and 4 or 5 Sacral. At the inferior end the two trunks converge and unite in a single ganglion, the **ganglion impar,** in front of the coccyx. The upper extremities of the two sympathetic trunks are prolonged into the cranium through the carotid canals as the **right** and **left internal carotid nerves,** which give off the **carotid** and **cavernous plexuses** and communicate with several cranial nerves. In each trunk, the

ganglia are connected or strung together by nerve filaments containing variously derived nerve fibres. Some of these fibres are derived from one ganglion and pass to and through another; others are derived from the spinal nerves by way of the white rami communicantes and ascend or descend in the gangliated cord before ending in relation to the cells of a ganglion, or passing through it to a more distant termination.

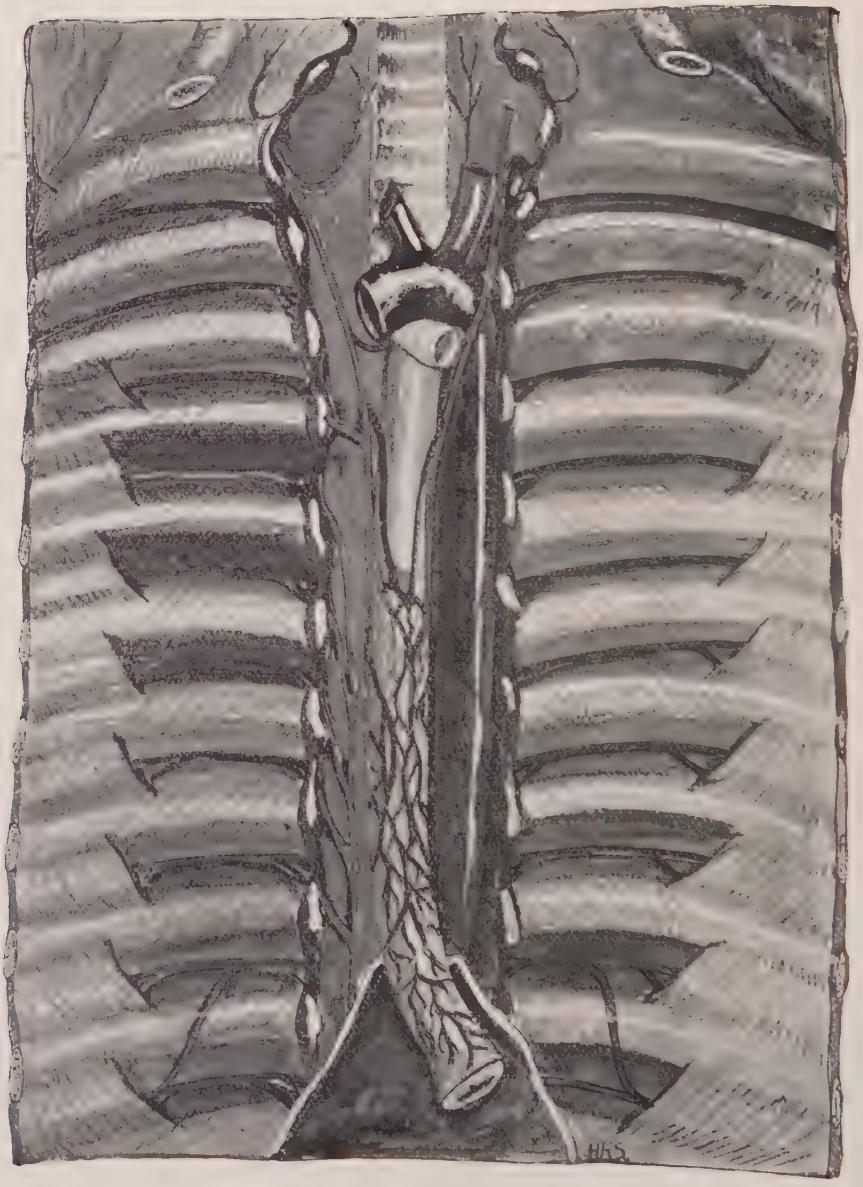

Fig. 70. Schema of Sympathetic and Esophageal Plexus.

The sympathetic trunks are united to the spinal nerves in two ways; each spinal nerve receives from a nearby sympathetic ganglion a branch called the **gray ramus communicans,** which carries non-medullated efferent and afferent fibres; the spinal nerves from the first thoracic to the first lumbar, inclusive, give off **white rami communicantes,** composed of medullated efferent and afferent fibres. The fibres of the white rami sometimes terminate in the nearest ganglion and sometimes pass through it to end in a more distant ganglion of the chain; those of the upper third of the thoracolumbar series have an upward tendency in the gangliated cord and some ascend as high as the superior cervical ganglion, while those of the lower two-thirds have a downward trend and reach the sacral ganglia. Thus the white rami, though limited to a little more than the middle half of the entire series of spinal nerves, come into relation with ganglia whose postganglionic fibres ramify every area of the body.

The second, third, and fourth sacral nerves give off white rami which resemble those of the thoracolumbar series, except that they pass the sacral ganglia to end in the collateral ganglia of the pelvis.

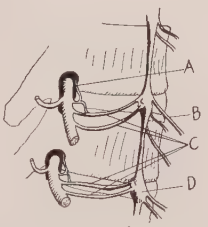

Fig. 71.
Schema of Sympathetic Ganglia, Rami Communicantes, Intervertebral Nerves, and Recurrent Branches.
A, Recurrent Branch; B, Branch to Viscera; C, Rami Communicantes; D, Sympathetic Ganglion.

(2) The three **prevertebral plexuses** are situated in front of the vertebral column; they are the **cardiac,** in the thorax, the **coeliac, solar,** or **epigastric,** in the upper part of the abdominal cavity, and the **hypogastric,** in the pelvis. Each is connected with the sympathetic trunks; each is a complex interlacement of nerve fibres derived from the sympathetic and from some of the cerebrospinal nerves; and each distributes numerous branches, through subplexuses, to the blood-vessels and viscera of its cavity.

(3) The **collateral ganglia** are numerous masses of nerve cells, situated in the prevertebral plexuses and subplexuses or in relation to the walls of the organs to be innervated. In this category are such widely different ganglia as the ciliary, spehnopalatine, and otic ganglia of the head, and the great semilunar ganglia of the coeliac plexus.

(4) The **connecting cords** may consist of delicate filaments or may reach a considerable size and be separetely named; as, the

three cervical cardiac nerves, or the three splanchnic nerves. They include all sympathetic nerve elements passing between sympathetic ganglia.

(5) The **terminal branches** are composed of postganglionic fibres, exclusively derived from sympathetic ganglia, and non-medullated. They are usually short but, as in the case of the fibres carried by the gray rami into the spinal nerves for distribution to the blood-vessels of the extremities, may be very long.

A more detailed description of the parts of the sympathetic follows:

CERVICAL SYMPATHETIC

This consists of three ganglia, named the **superior, middle,** and **inferior cervical ganglia,** on either side of the median line. They lie in front of the transverse processes of the cervical vertebrae; the superior in front of the second and third cervical transverse processes; the middle in front of the sixth; and the inferior between the base of the last cervical transverse and the head of the first rib.

The **superior cervical ganglion** is a reddish-gray, fusiform, structure, sometimes broad and flattened and sometimes constricted at intervals; it is considered as the coalescence of four ganglia corresponding to the four upper cervical nerves. It is connected to these four nerves by gray rami but receives no white rami from them. It lies in front of the longus capitis muscle and just behind the sheath of the internal carotid artery and internal jugular vein. Its branches are numerous and may be divided into **inferior, lateral, medial, anterior,** and **superior.**

The **inferior branch** is that which communicates with the middle cervical ganglion.

The **lateral branches** consist of four gray rami communicantes, one to each of the four upper cervical nerves, and filaments to the ganglion nodosum of the vagus, to the hypoglossal nerve, and to the jugular ganglion of the vagus and the petrous ganglion of the glossopharyngeal; the filaments to the last two named ganglia are united for a distance as one nerve, the **jugular nerve.**

The **medial branches** are the **laryngo-pharyngeal branches** and the **superior cardiac nerve.** The former pass to the side of the pharynx and join with branches from the glossopharyngeal, vagus, and external laryngeal branch of the vagus, to form the pharyngeal plexus. The **superior cardiac nerve** arises from the superior cervical ganglion by one or two branches and sometimes receives a

filament from the trunk between the first and second ganglia. It passes almost vertically downward in the neck in front of the longus colli muscle and behind the common carotid artery; it crosses in front of the inferior thyroid artery and the recurrent nerve, and thereafter the courses of the right and left nerves differ. The right nerve passes close to the subclavian artery, and follows the innominate artery to the back of the arch of the aorta, where it enters into the deep portion of the cardiac plexus. It receives a filament from the recurrent nerve, one or two from the vagus, and several from the external laryngeal nerve. It communicates with the thyroid branches from the middle cervical ganglion. The left superior cardiac nerve passes in front of the left common carotid artery, and crosses the left side of the arch of the aorta to the superficial portion of the cardiac plexus.

The **anterior branches** spread out upon the common carotid artery and the external carotid artery and its branches, in thin plexuses, within which some small ganglia are sometimes present. The plexus around the external maxillary artery sends a branch to the submaxillary ganglion; that on the middle meningeal artery gives a filament to the otic ganglion, and another, the external petrosal nerve, to the genicular ganglion of the facial nerve.

The **superior branch** is given off from the upper part of the ganglion in such a manner as to appear to be its superior continuation. It is known as the **internal carotid nerve.** It is reddish-gray in color. It ascends beside the internal carotid artery and with it enters the carotid canal in the temporal bone, where it divides into two branches, which are placed one medial to and the other lateral to the artery. The lateral branch is the larger; it gives filaments to the internal carotid artery and forms the **internal carotid plexus.** The medial division also gives filaments to the internal carotid artery, and continues upward to form the **cavernous plexus.**

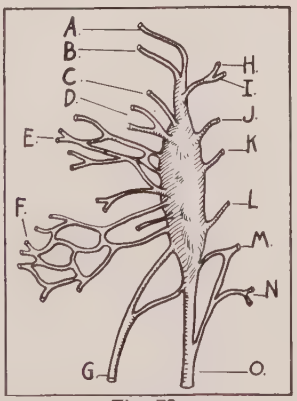

Fig. 72.
Superior Cervical Ganglion. A, To Carotid Plexus, Tympanic Branch of Glossopharyngeal, and 6th Nerve; B, To Cavernous Plexus, 5th Nerve, 4th Nerve, Sphenopalatine Ganglion, 3rd Nerve, and Ciliary Ganglion; C, To Trunk Ganglion of Vagus; D, To Hypoglossal n.; E, Accompanying Branches to External Carotid Artery; F, To Pharyngeal Plexus; G, Superior Cardiac n.; H, To Root Ganglion of Vagus; I, To Petrosal Ganglion of Glosso-Pharyngeal n.; J, To 1st Cervical n.; K, to 2nd Cervical n.; L, To 3rd Cervical n.; M, To 4th Cervical n.; N, To 5th Cervical n.; O, To Middle Cervical Ganglion.

The **internal carotid plexus** (*carotid plexus*) is placed on the lateral side of the artery; it sometimes has a small **carotid ganglion,** probably an aberrant

fragment of the superior cervical ganglion. This plexus gives filaments to the semilunar ganglion of the trigeminal, the abducent nerve, the sphenopalatine ganglion, and the tympanic branch of the glossopharyngeal nerve, and distributes branches to the wall of the internal carotid artery.

The one or two filaments to the abducent nerve are given off to that nerve as it lies upon the lateral side of the internal carotid artery. The branch to the sphenopalatine ganglion, the **deep petrosal nerve,** leaves the plexus on the lateral side of the artery, passes through the cartilage in the foramen lacerum, and joins the greater superficial petrosal nerve to form the nerve of the pterygoid canal (*Vidian nerve*), which traverses the pterygoid canal and enters the back part of the sphenopalatine ganglion. The **caroticotympanic branch,** which may consist of several filaments, is given to the tympanic branch of the glossopharyngeal.

The **cavernous plexus** is formed chiefly by the splitting up of the medial division of the internal carotid nerve, in the cavernous sinus, beside the sella turcica of the sphenoid bone. It gives branches to the oculomotor, trochlear, ophthalmic, and abducent nerves, and to the ciliary ganglion, and distributes filaments to the wall of the internal carotid artery. The branches to the **ciliary ganglion** leave the anterior part of the plexus and enter the orbit through the superior orbital fissure; they sometimes pass to the ganglion directly, and sometimes join the nasociliary branch of the ophthalmic nerve.

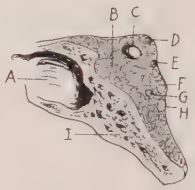

Fig. 73.
Nerve Trunks in the Cavernous Sinus.
A, Sphenoidal Sinus; B, Cavernous Sinus; C, Carotid Artery; D, Oculomotor n.; E, Trochlear n.; F, Ophthalmic n.; G, Abducent n.; H, Maxillary n.; I, Sphenoid Bone.

From both the carotid and cavernous plexuses, **terminal branches** follow the anterior and middle cerebral arteries, and the ophthalmic artery, in plexiform arrangement. On the cerebral arteries they run as far as the pia mater, and on the ophthalmic they pass into the orbit and follow each of the branches of the artery. Filaments from the two sides meet on the anterior communicating artery.

The importance of the internal carotid nerve and its various branches can hardly be overestimated, since through it a pathway is established whereby the spinal nerves, through the superior cer-

vical ganglion, may influence the distribution of blood, and thus the process of nutrition, of the brain and of many cranial nerves and their special end-organs.

The **middle cervical ganglion** is occasionally absent, and when present is the smallest of the three. It lies in front of the inferior thyroid artery, at the side of the sixth cervical vertebra, and is probably formed by a coalescence of two ganglia belonging originally to the fifth and sixth cervical nerves. It gives off two gray rami, one to the fifth and one to the sixth cervical nerve, and gives origin to the middle cardiac nerve.

The **middle cardiac nerve** is the largest of the three cervical cardiac nerves. It arises from the middle cervical ganglion or, in some cases, from the trunk between the middle and inferior ganglia. Both nerves descend to join the deep portion of the cardiac plexus but their course differs on the two sides. The right middle cardiac nerve descends behind the common carotid artery, and at the root of the neck passes either in front of or behind the subclavian artery; it then descends on the trachea, receives filaments from the recurrent nerve, and enters the right half of the deep part of the cardiac plexus. The left middle cardiac nerve enters the chest between the left common carotid and subclavian arteries, and unites with the left half of the deep portion of the cardiac plexus.

The **inferior cervical ganglion** is placed between the base of the transverse process of the last cervical vertebra and the neck of the first rib, medial to the costo-cervical artery. It is larger than the middle cervical ganglion, of irregular shape, and is sometimes fused with the first thoracic (*stellate*) ganglion; it is probably a coalescence of two ganglia once belonging to the seventh and eigth cervical nerves. Its communicating filaments with the middle cervical ganglion form a loop, the **ansa subclavia,** upon the subclavian artery to which branches are distributed. Gray rami are given by the inferior cervical ganglion to the seventh and

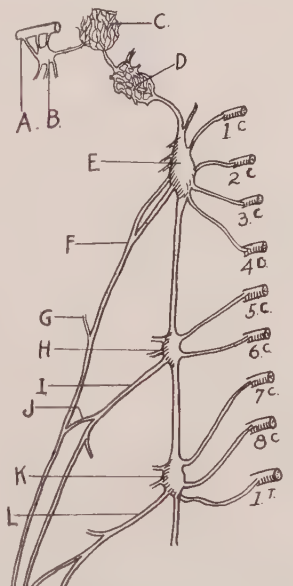

Fig. 74. Schema of Cervical Cardiac Nerves.
A, Maxillary n.; B, Spheno-Palatine Ganglion; C, Cavernous Plexus; D, Carotid Plexus; E, Superior Cervical Ganglion; F, Superior Cervical Nerve; G, Branch from External Pharyngeal n.; H, Middle Cervical Ganglion; I, Middle Cervical n.; J, Communicating Branch; K, Inferior Cervical Ganglion; L, Inferior Cervical n.

eighth cervical nerves, branches are given to blood-vessels, and the inferior cardiac nerve arises in this ganglion.

The **inferior cardiac nerve** usually arises from the inferior cervical ganglion but may arise from the first thoracic ganglion, or from a junction of the two. It descends behind the subclavian artery and along the front of the trachea, to join the deep portion of the cardiac plexus. It communicates freely with the middle cardiac nerve and with the recurrent laryngeal branch of the vagus.

The **branches to blood-vessels** form plexuses on the subclavian artery and its branches. That plexus which accompanies and supplies the vertebral artery follows the basilar, posterior cerebral, and cerebellar arteries, and thus shares with the internal carotid nerve the control of the blood supply to the brain. A plexus follows the inferior thyroid artery to the thyroid gland to supply its blood-vessels, and this plexus communicates with the recurrent and external laryngeal nerves, with the superior cardiac nerve, and with the plexus on the common carotid artery.

THE THORACIC SYMPATHETIC

This usually consists of twelve ganglia, one to correspond with each thoracic nerve, but occasionally two ganglia may have coalesced, making the number eleven. These ganglia lie close to the heads of the ribs and are covered by the costal plexus, except that the last two are more anterior and lie beside the bodies of the eleventh and twelfth thoracic vertebrae, making a transition in position between that of the thoracic and that of the lumbar ganglia. All the thoracic ganglia are connected together by the sympathetic trunk, as the first thoracic is connected with the inferior cervical and the last thoracic with the first lumbar ganglion. The first is the largest of the thoracic ganglia, the rest being quite small. The first may be blended with the inferior cervical ganglion.

Each thoracic ganglion is connected to its corresponding spinal nerve by a gray ramus communicans and a white ramus.

The **branches** of the thoracic ganglia may be divided into two groups; the upper group, proceeding from the upper five ganglia,

are small, and are directed forward to the thoracic aorta and its branches. Filaments from the second, third, and fourth ganglia enter the posterior pulmonary plexus.

The branches from the lower seven thoracic ganglia are large, white nerves which distribute branches to the aorta and unite to form three important nerves: the greater, the lesser, and the least splanchnic nerves.

The **greater splanchnic nerve** (*great splanchnic nerve*) is a large nerve, firm in texture, and whitish in color. It is formed by the union of branches from the thoracic ganglia from the fifth to the ninth or tenth inclusive. It begins above as a slender, descending cord in front of the bodies of the vertebrae, and increases in size as it passes downward, by the successive accession of branches from the ganglia it passes. Fibres of this nerve have been shown as arising also in the ganglia as high as the second or third thoracic; these descend in the sympathetic trunk as far as the fifth before they emerge. After being fully formed by the acquisition of all its component parts, the greater splanchnic nerve penetrates the crus of the diaphragm and ends in the coeliac ganglion. A **ganglion splanchnicum** is seen on the nerve at the level of the eleventh or twelfth thoracic vertebra.

The **lesser splanchnic nerve** is formed by branches from the ninth and tenth, and sometimes from the eleventh, thoracic ganglia, and from the trunk which connects them. It penetrates the diaphragm with the greater splanchnic and is terminated in the aorticorenal ganglion.

The **least splanchnic nerve** arises from the last thoracic ganglion, penetrates the diaphragm, and ends in the renal plexus.

These three nerves are composed largely of spinal nerve fibres which have passed through the ganglia uninterrupted, and which terminate in the ganglia at the ends of the splanchnic nerves. They also contain postganglionic fibres from the tho-

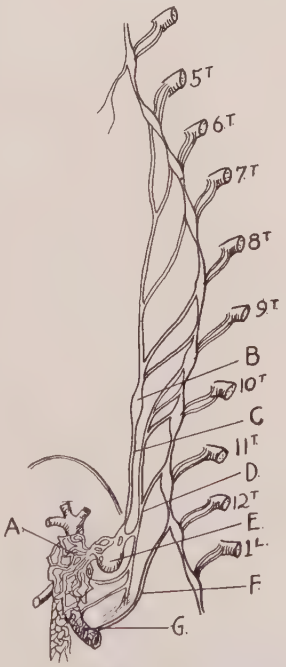

Fig. 75. Schema of Sympathetic Trunk and Splanchnic Nerves.
A, Coeliac Plexus; B, Splanchnic Ganglion; C, Great Splanchnic n.; D, Lesser Splanchnic n.; E, Semilunar Ganglion; F, Least Splanchnic n.; G, Renal Plexus.

racic ganglia; both afferent and efferent elements are present but the latter are the more numerous.

The splanchnic nerves establish a pathway of control between the cerebrospinal system and the abdominal viscera. Through the coeliac plexus and its subdivisions, these nerves influence every important organ in the abdominal cavity, just as the three cervical cardiac nerves influence every thoracic organ. There is a marked similiarity in the arrangement of these two sets of nerves. The cervical cardiac nerves, like the splanchnics, are three in number; they arise from all the cervical ganglia just as the splanchnics are connected with all, or nearly all, the thoracic. Each set supplies one of the great cavities of the body and, through one of the great prevertebral plexuses and its subdivisions, ultimately reaches every important organ in that cavity. The more detailed relation of the spinal nerves to the various parts of the area of distribution of the splanchnics will be taken up in the section on Physiology of Nerves. (See page 234.)

THE LUMBO-ABDOMINAL SYMPATHETIC

The four lumbar ganglia, connected by communicating cords, and forming the lumbo-abdominal portion of the sympathetic trunk, are situated in front of the sides of the lumbar vertebrae, along the medial border of the psoas major muscle. Each lumbar ganglion gives off gray rami communicantes, one of which is received by each lumbar spinal nerve. White rami communicantes pass from the first and second, and occasionally the third and fourth lumbar nerves to the corresponding ganglia; these rami are of some length and follow the lumbar arteries around the sides of the vertebral bodies.

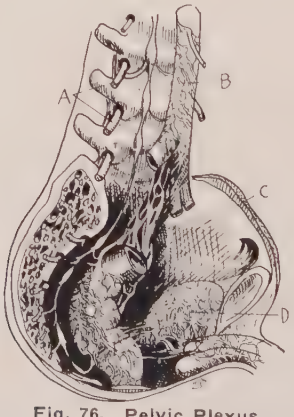

Fig. 76. Pelvic Plexus.
A, Intervertebral Nerves; B, Aortic Plexus; C, Rectum and Hypogastric Plexus; D, Bladder and Vesical Plexus.

The **branches** of the lumbar ganglia are distributed to the aortic plexus and the hypogastric plexus; the former pass in front of the aorta, the latter descend in front of the common iliac arteries into the pelvis.

Pelvic Portion of Trunk.

Either four or five small sacral ganglia are placed in front of the sacrum and connected to each other and to the lumbar portion of the trunk above, by communicating cords. The right and left sympathetic trunks converge below to meet in front of the coccyx in a small ganglion, the **ganglion impar.** The sacral ganglia give gray rami to the sacral and coccygeal nerves but no true white rami are given off in this region. Visceral branches arise from the second, third and fourth sacral nerves, and run directly to the pelvic plexus, where their terminals come into relation with the cells of collateral ganglia; they are made up of preganglionic fibres and are regarded as analagous to the white rami.

The **branches** of the pelvic portion of the trunk communicate in front of the sacrum with those from the opposite side; some branches from the first two ganglia go to join the pelvic plexus, while others form a plexus which follows the middle sacral artery and gives filaments to the coccygeal body.

The Great Prevertebral Plexuses.

The great sympathetic plexuses are the **cardiac,** the **coeliac,** and the **hypogastric,** situated in the thoracic, abdominal, and pelvic cavities, respectively. Each is an aggregation of interlaced nerves and ganglia, from which numerous subplexuses and branches are given off to the viscera.

Each plexus contains, in addition to sympathetic efferent and afferent fibres which leave and enter it, fibres derived from the spinal nerves by way of the white rami communicantes; the cardiac and coeliac plexuses receive fibres from certain cranial nerves, and the hypogastric plexus receives those medullated fibres previously referred to as arising from S2, S3, and S4, and having the characteristics of white rami. Each of the three great plexuses, while primarily a plexus of sympathetic nerves and ganglia, is in reality a mingling of sympathetic and cerebrospinal neurons; the ganglia are interposed cell stations in the course of pathways between the central nerve system and the periphery.

THE CARDIAC PLEXUS

This plexus is formed by a mingling of branches from the right and left vagus nerves with sympathetic fibres derived from the three cervical ganglia by the superior, middle, and inferior cardiac nerves. Preganglionic fibres leave the first three spinal nerves, but particularly the second, enter the gangliated cord, and ascend to terminate by synapsis with the dendrites of cells in the three cervical ganglia. Their postganglionic fibres pass in the three cervical cardiac nerves. The plexus is situated at the base of the heart and is divided into a superficial and a deep part, which are closely connected. The **superficial part** lies in the concavity of the arch of the aorta, in front of the right pulmonary artery. It is made up of the left superior cardiac nerve of the sympathetic and the lower superior cervical cardiac branch of the left vagus. A small ganglion, the **ganglion of Wrisberg**, is sometimes present immediately under the arch of the aorta and to the right of the ligamentum arteriosum. The superficial part of the cardiac plexus gives off branches to the deep plexus, to the anterior coronary plexus, and to the left anterior pulmonary plexus. The **deep part** of the cardiac plexus is formed by all the cardiac nerves except the two described as entering the superficial part; i. e., all the cervical cardiac nerves of the sympathetic except the left superior, and all the cardiac branches of the two vagus nerves except the lower of the two superior cervical cardiac branches of the left vagus.

Branches from the **right** half of the deep portion of the cardiac plexus pass some in front of the right pulmonary artery and others behind it. Those which pass in front send filaments to the anterior pulmonary plexus and then continue to enter into the formation of the anterior coronary plexus; those behind give branches to the right atrium and then enter into the posterior coronary plexus.

The **left** half of the deep plexus communicates with the superficial part, gives fibres to the left atrium and to the anterior pulmonary plexus, and is then continued to form part of the posterior coronary plexus.

The **posterior coronary plexus** accompanies the left coronary artery and is larger than the anterior; its fibres are derived chiefly from the left half of the deep part of the cardiac plexus, but it receives a few from the right half. Its branches are distributed to the left atrium and ventricle.

The **anterior coronary plexus** derives its fibres both from the superficial and the deep part of the cardiac plexus, and accom-

Fig. 77. Cardiac Plexus.

panies the right coronary artery. Its branches are distributed to the right atrium and ventricle.

The **anterior pulmonary plexus** is formed on the anterior aspect of the root of the lung, by a mingling of branches from the deep part of the cardiac plexus with the anterior bronchial branches of the vagus and sympathetic cords from the second, third, and fourth thoracic ganglia, more especially the third. Its branches are distributed to the bronchi and lung.

The **posterior pulmonary plexus** is placed at the posterior surface of the root of the lung and its branches follow the bronchial tubes in their ramifications through the lungs. It is made up of fibres from the posterior bronchial branches of the vagus and sympathetic nerves from the upper four thoracic ganglia, especially the first and third ganglia.

THE COELIAC PLEXUS

The **Coeliac Plexus** (*solar plexus, epigastric plexus*) lies in the upper back part of the abdomen, surrounding the coeliac artery and the root of the superior mesenteric artery. It is level with the upper part of the first lumbar vertebra, and is behind the stomach

and the omental bursa, in front of the crura of the diaphragm and the upper part of the abdominal aorta, and between the suprarenal glands. It is the largest of the three prevertebral plexuses.

The coeliac plexus is made up of two large ganglia, the **coeliac ganglia,** and the sympathetic fibres arising from them in a dense interlacement, of the greater and lesser splanchnic nerves of both sides, and of fibres from the right vagus nerve and the phrenic nerves. Its branches are so arranged as to accompany and supply the abdominal aorta and its arterial offshoots, and their subdivisions. Ten **subplexuses** are described as springing from the coeliac plexus; each of these is rather a subdivision or a continuation than a branch. The entire plexus, with its subdivisions, makes a sort of reticulum around the large abdominal arteries. (*See frontispiece.*)

The ten subplexuses connected with the coeliac plexus are the

Phrenic	Renal
Hepatic	Spermatic
Lienal	Superior mesenteric
Superior gastric	Abdominal aortic
Suprarenal	Inferior mesenteric

The **Coeliac Ganglia** (*semilunar ganglia*) are two large masses, of irregular shape, and appearing somewhat like lymph glands. They are situated on either side of the median line in front of the crura of the diaphragm and near the suprarenal glands; the right is behind the vena cava. The greater splanchnic nerve enters the upper part of each ganglion. The lower part is partly separated from the rest by a constriction and is termed the **aorticorenal ganglion;** it is joined by the lesser splanchnic nerve and gives off most of the renal plexus.

The **phrenic plexus** supplies the diaphragm and gives some fibres to the suprarenal gland. It is given off from the upper part of the coeliac ganglion and receives a few branches from the phrenic nerve; its right half is larger than its left. A small ganglion, the **ganglion phrenicum,** appears at the junction of the phrenic nerve with the plexus. The phrenic plexus communicates with the suprarenal and hepatic plexuses, and gives fibres to the inferior vena cava.

The **hepatic plexus** is the largest subdivision of the coeliac and receives branches from both the left vagus and right phrenic nerves. It accompanies the hepatic artery to supply the liver, and follows the branches of that vessel and the portal vein within the

liver substance. A part of the hepatic plexus follows the gastroduodenal artery and develops the **inferior gastric plexus** on the right gastroepiploic artery along the greater curvature of the stomach, uniting with filaments from the lienal plexus. That part of the coeliac ganglion from which the hepatic plexus arises receives preganglionic fibres by way of the white ramus from the fourth thoracic nerve in particular, and to a lesser extent from the subjacent three spinal nerves.

The **lienal plexus** (*splenic plexus*) accompanies the splenic artery to the spleen and gives off subsidiary plexuses which run along the branches of that artery to the greater curvature of the stomach and to the pancreas. It is made up chiefly of fibres from the coeliac plexus and coeliac ganglion but also carries some fibres derived from the right vagus nerve. The fibres from the coeliac ganglion and plexus are the axons of cells which receive preganglionic fibres by way of the greater splanchnic nerve and white rami communicantes from the eighth and ninth thoracic spinal nerves. The ninth appears to be more intimately connected with the spleen; the eighth with the pancreas.

The **superior gastric plexus** runs with the left gastric artery along the lesser curvature of the stomach, receives filaments from the left vagus, and is distributed to the stomach wall.

The **suprarenal plexus** is distributed to the suprarenal gland, more especially to its medullary portion. It derives from the coeliac plexus and coeliac ganglion, and receives filaments from the phrenic and greater splanchnic nerves. A ganglion is present where the latter nerve joins the plexus. The portion of the greater splanchnic nerve which reaches this plexus probably derives from the tenth thoracic ganglion and from the ninth or tenth thoracic spinal nerves by way of the white rami communicantes.

The **renal plexus** is derived from the coeliac ganglion, the aortic plexus, and the aorticorenal ganglion; it is joined by the least splanchnic nerve. Its nerves number fifteen or twenty and have a number of small ganglia upon them. The preganglionic fibres which enter this plexus, and which communicate in the aorticorenal ganglion with its postganglionic fibres, arise from the tenth, eleventh, and twelfth thoracic spinal nerves. The plexus follows the renal artery into the kidney and supplies that organ; branches are also given to the spermatic plexus and to the inferior vena cava.

The **spermatic plexus** arises from the renal plexus and branches from the aortic plexus. It follows the internal spermatic artery to

the testes. In the female, the **ovarian plexus** arises similarly and is distributed to the ovary and to the fundus of the uterus.

The **superior mesenteric plexus** is in reality a downward prolongation of the coeliac plexus, and surrounds the superior mesenteric artery. It follows the artery into the mesentery and splits up into numerous subplexuses which accompany the arterial branches and supply filaments to the pancreas, the small intestine, and the colon. A ganglion is present near the origin of the superior mesenteric artery. This plexus receives a small branch from the right vagus nerve.

The **abdominal aortic plexus** is made up of branches derived from both sides of the coeliac plexus and coeliac ganglia and from the lumbar ganglia of the sympathetic trunk. It surrounds the aorta, chiefly at front and sides, between the origins of the superior and inferior mesenteric arteries. From it are derived parts of the spermatic, the inferior mesenteric, and the hypogastric plexuses; filaments are given to the inferior vena cava. The aortic plexus is the chief link between the coeliac and hypogastric plexuses, and, with its connecting cords and subplexuses, completes a continuous chain of sympathetic nerve elements which closely invests, and controls, the abdominal aorta and its branches. The parallel distribution of arterial and nervous systems is in this region most marked.

The **inferior mesenteric plexus** is derived chiefly from the aortic plexus and from the lumbar ganglia. It surrounds the inferior mesenteric artery, and sends offshoots to all its branches. The ultimate distribution from this plexus is to the **left colic** and **sigmoid** plexuses, which supply the descending and sigmoid portions of the colon; and the **superior hemorrhoidal** plexus, which supplies the rectum, and unites in the pelvis with branches from the pelvic plexuses.

THE HYPOGASTRC PLEXUS

The hypogastric plexus lies between the two common iliac arteries, in front of the fifth lumbar vertebra and the upper part of the sacrum. It is formed by branches from the lumbar ganglia and by descending sympathetic cords from both sides of the aortic plexus. Below, it divides into the right and left **pelvic plexuses,** and these receive the visceral branches of the second, third, and fourth sacral nerves.

THE PELVIC PLEXUSES

The **Pelvic Plexuses** are situated at the sides of the rectum in the male and at the sides of the rectum and vagina in the female. They are formed on either side by the bifurcation of the hypogastric plexus, by the visceral branches from S2, S3, and S4, and by filaments from the first two sacral ganglia. Numerous small ganglia are found at the junction points of these various nerves. Probably all the visceral branches from the sacral nerves terminate in these ganglia, and all the emerging branches of the hypogastric and pelvic plexuses are postganglionic. The branches of the pelvic plexuses are distributed to all the pelvic viscera; they follow the branches of the hypogastric artery. The subplexuses of the pelvic plexus are: the **middle hemorroidal, vesical, prostatic, vaginal,** and **uterine plexuses.**

The **middle hemorroidal plexus** leaves the upper part of the pelvic plexus and joins with branches from the superior hemorroidal plexus to supply the rectum.

The **vesical plexus** leaves the front of the pelvic plexus, carrying numerous fibres, many of which are derived from the sacral nerves. Its branches accompany the vesical arteries and are distributed to the sides and fundus of the bladder, to the seminal vesicles, and to the ductus deferentes; the latter branches join, on the spermatic cord, with branches of the spermatic plexus.

The **prostatic plexus** leaves the lower part of the pelvic plexus and is distributed to the prostate gland, seminal vesicles and the corpora cavernosa of the penis and urethra. The nerves to the corpora cavernosa are two sets, the **lesser cavernous nerves,** which leave the forepart of the prostatic plexus, join with branches of the pudendal nerve, and penetrate the fibrous covering of the penis near its root, and the **greater cavernous nerve,** which arises similarly, passes forward along the dorsum of the penis, joins the dorsal nerve of the penis, and is distributed to the corpora cavernosa. All the nerves of the prostatic plexus are large.

The **vaginal plexus,** like the vesical, carries a large percentage of spinal nerve fibres. It arises from the lower part of the pelvic plexus and is distributed to the erectile tissue of the vestibule and to the clitoris.

The **uterine plexus** follows the uterine artery to the side of the uterus, between the layers of the broad ligament, and communicates with the ovarian plexus.

THE CRANIAL SYMPATHETICS

This name is applied to certain groups of nerve fibres which traverse the third, seventh, ninth, and tenth cranial nerves, because they are non-medullated; because they innervate glands and non-striated muscle tissue; and because they are involuntary in function.

Efferent fibres of this variety are found in the oculomotor nerve, and both afferent and efferent in the facial, glossopharyngeal, and vagus nerves.

The **oculomotor sympathetics** are efferent and have their real origin in small cells in the ventral part of the oculomotor nucleus in the tegmentum of the mid-brain. They traverse the third nerve until, within the orbit, they are given off to the ciliary ganglion. In this ganglion they terminate by forming synapses with neurons whose axons (*postganglionic*) pass to the eyeball as the short ciliary nerves. These are motor to the ciliaris and sphincter pupillae muscles.

In the facial nerve, sympathetic efferent fibres apparently arise in the small cells of the facial nucleus and proceed with the nerve and its chorda tympani branch to the submaxillary ganglion. Here they terminate in relation to cells whose axons (*postganglionic fibres*) conduct impulses to the submaxillary and sublingual glands to control secretion and the dilation of blood-vessels. The preganglionic fibres of this group may originate in the superior salivatory nucleus, scattered dorsomedial to the facial nucleus, instead of in the facial nucleus itself. Preganglionic fibres of the facial nerve also pass by the greater superficial petrosal nerve to the sphenopalatine ganglion; there they enter into arborizations with cells whose axons run with the maxillary nerve as vasodilator and secretory fibres to the nose, soft palate, tonsils, uvula, roof of the mouth, upper lip and gums, parotid and orbital glands.

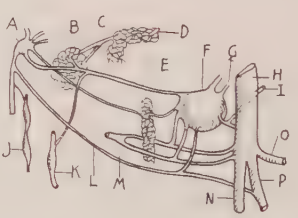

Fig. 78. Otic Ganglion.

A, Genicular Ganglion; B, Large Superficial Petrosal n.; C, Tympanic Plexus; D, Carotid Plexus; E, Small Superficial Petrosal n.; F, Otic Ganglion; G, Nerves to Tensor Tympani and Tensor Veli Palatini; H, Mandibular n.; I, Nerve to Internal Pterygoid Muscle; J, Vagus n.; K, Glossopharyngeal n.; L, Chorda Tympani n.; M, Auriculo-Temporal n.; N, Inferior Alveolar n.; O, Motor Division of Trigeminal n.; P, Lingual n.; Q, Middle Meningeal Plexus.

It is believed that some afferent sympathetic neurons, having their cells of origin in the genicular ganglion, are present in the facial nerve.

Glossopharyngeal Sympathetics. These are both efferent and afferent. The efferent fibres probably originate either in the dorsal nucleus or in a separate nucleus, the inferior salivatory nucleus, located near the dorsal nucleus. The fibres are preganglionic and run into the tympanic branch of the glossopharyngeal nerve and thence with the small superficial petrosal nerve to the otic ganglion. From this ganglion, and related as postganglionic fibres to the foregoing, vasodilator and secretory fibres supply the parotid gland, the mucous membrane and glands on the tongue, the floor of the mouth, and the lower gums. Afferent sympathetic fibres of the glossopharyngeal are supposed to originate in the cells of the superior or inferior ganglion and to end in the dorsal nucleus.

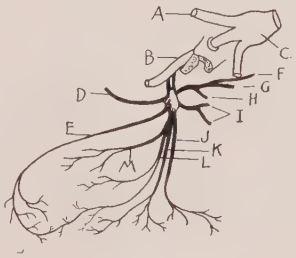

Fig. 79

Spheno-Palatine Ganglion. A, Ophthalmic n.; B, Maxillary n.; C, Semilunar Ganglion; D, Superior Nasal n.; E, Naso-Palatine n.; F, to Facial Nerve; G, Large Superficial Petrosal n.; H, From Carotid Plexus; I, Pharyngeal n.; J, Dorsal Palatine n.; K, Middle Palatine n.; L, Ventral Palatine n.; M, Nasal Branch.

Vagal Sympathetics. These are both efferent and afferent. The efferent fibres probably arise in the dorsal nucleus (*nucleus ala cinerea*) pass with the trunk and branches of the vagus, and terminate, as preganglionic fibres, in numerous sympathetic ganglia located near the organs to be supplied; the postganglionic fibres from the cells of these ganglia complete the pathway. Some of these vagal sympathetic fibres are inhibitory to the heart; they end in ganglia in the heart wall, especially the atrium. Other efferent sympathetic fibres are motor to the smooth muscle of the esophagus, stomach, small intestine, and part of the large intestine; they terminate in the plexuses of Auerbach, from which postganglionic fibres complete the pathway. Still others reach the muscles of the bronchial tubes, and the gall-bladder and bile-ducts. Secretory fibres to the stomach and pancreas pass in the vagus and there may be others yet unknown.

It is probable that the vagus contains afferent sympathetic fibres less numerous than the efferent but carrying impressions centralward from all the organs supplied with efferent sympathetic fibres through that nerve. They originate in the cells of the jugular ganglion and ganglion nodossum and perhaps terminate in the dorsal nucleus, perhaps in the nucleus of the tractus solitarius.

EMBRYOLOGY
OF THE
NERVOUS SYSTEM

The adult relationship of the parts of the human nervous system to each other and to the other structures of which the body is composed can only be clearly understood if the manner of their development is known, and their relationship at various stages of that development. It is not enough that we known what a nerve structure is; we must know how it became what it is and through what changes of form and function it has passed.

A portion of the development of the human nerve system takes place in the individual after birth. Organs which at birth are comparatively rudimentary continue to grow and change until they assume an important role in the performance of the general function of the system. Some elements, like the cerebrospinal neurons, although measurably well formed at birth, do not assume their function until their special coverings (*medullary sheaths*) are completed, which takes place within the first few months of extrauterine life. The most important development, however, takes place during the pre-natal period. During that period the human individual develops from a single fertilized ovum to a highly organized body, containing within itself all the organs necessary for life and all the germinal cells required for growth to adult stature. To the study of the intra-uterine period of growth the term **Embryology** is applied.

The arrival of the human nerve system at its present state of dominance among the tissues, its transcendence in delicacy of structure and in functional importance over other tissues, has proceeded through an inconceivably long phylogenetic past, by a series of successive steps which, singly, are almost imperceptible but which, aggregating age by age, become visible as stages of development in complexity and power. These changes have kept pace with the evolution of the animal organism.

The study of a limited amount of comparative embryology therefore throws some light upon human development. It has been discovered that each human individual, in the earliest phases of development, reproduces, to some extent, the forms characteristic

of the various major stages of race life. Thus, in an early stage, transient gill-pouches appear which are like to those of fishes; the heart passes through temporary changes similar to those in certain lower animals. Some of these remote ancestral characteristics occasionally persist and result in the formation of monsters of various types; others, less marked, tend to persist in all human individuals, although now useless in the body economy or nearly so. The coccyx, remnant of an ancestral caudal appendage, is one; the vermiform appendix, vestigial remnant of an ancient caecal pouch, is another. A certain amount of **phylogeny** is interlinked with embryology.

GENERAL EMBRYOLOGY

The period of pre-natal, or intra-uterine, development of the human individual is divided into three sub-periods; (1) the period of the **zygote,** or pre-embryonic period, which lasts about fourteen days and during which there is no definite separation between embryonic and non-embryonic portions; (2) the period of the **embryo,** which lasts from the end of the fourteenth day to about the end of the second month, and during which the mass is divided into a distinct embryonic and a non-embryonic portion but does not assume a plainly human form; and (3) the period of the **foetus.** This period begins at the end of the second month and continues until birth; in it, the embryonic portion assumes and retains a human form. The entire period of intra-uterine life occupies nine lunar months.

Structure of Cells

Since the human body is developed by the reproduction and differentiation of animal cells, it is necessary to consider briefly the makeup and characteristics of such cells, as a preliminary to the description of the formation of the zygote.

All animal cells resemble each other, at least at some time in their lives, in certain particulars, and share some common properties. In time, these cells may take on different characteristics in accordance with their situation in the body and the functional demands upon them.

All the essential parts of an animal cell consist of a substance called **protoplasm,** which is a semifluid, viscous, irritable, contractile material. It is the physical basis of all life; that is, it is the one

substance through which life directly expresses itself in a manner perceptible to human intelligence. Its chemical constituents are C, H, N, O, and S, combined together in varying proportions to form different kinds of protoplasm which may carry different names. For example, the cell body is made up of **cytoplasm,** which is of two kinds, **spongioplasm,** or **cytoreticulum,** in the form of a network or framework, and the **hyaloplasm,** or **cytolymph,** a more fluid portion occupying the interstices of the spongioplasm.

The parts of the cell body are (a) the **nucleus** with its **nucleolus;** (b) the **centrosome** with its **centrioles;** and (c) the **mitochondria.**

The **nucleus** lies within the cytoplasm. It consists of **karyoplasm,** which presents a reticulated portion, the **karyo-reticulum,** and a more fluid part, the **karyolymph.** The karyoplasm is made up of a non-stainable or achromatic part called **linin,** and a stainable portion called **chromatin.** It is to observation of the changes which take place in the arrangement of the chromatin particles, that our knowledge of the process of cell reproduction is due.

During the rest periods the chromatin is broken up into small particles which lie in close relation with the linin network. During cell division, these particles are strung together into thread-like aggregations which break up into a number of segments called **chromosomes.** In the human, the typical number of chromosomes in a cell is 48; probably each animal species has a definite number. The nucleus, during the resting period, has a distinct membrane.

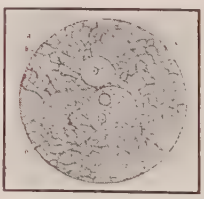

Fig. 80. Drawing of an Animal Cell. A, Cell Body; B, Centrosome; C, Centriole; D, Nucleolus; E, Nucleus.

The **nucleolus** is a spherical vessicle which lies in the karyolymph during the resting periods of the cell but which disappears during cell division. The **centrosome** is a clear spherical area of cytoplasm which usually lies near the nucleus. In its interior lie one or two deeply staining bodies called **centrioles,** and around it the cytoplasmic granules are arranged in radial lines. In cell division, the centrosome plays an important part, in some cases disappearing before the cell divides, but in ordinary cell division dividing before the division of the remainder of the cell. The mitochondria are minute particles which form a definite part of the structure of the spermatozoon or male gamete, and are believed to play an important part in the life-history of the cell.

LIFE-HISTORY OF ANIMAL CELLS

Reproduction of Cells.

Every animal cell is formed by the separation into parts of a pre-existing cell. This cell is called the **mother** cell and the results of its division **daughter cells**; these latter possess all the capabilities of the mother cell. Ordinary tissue cells come into being by the division of a mother cell into two equal and similar parts; each grows, performs its function, and ceases to exist either by dividing into two daughter cells or by disintegrating into non-living particles.

While cell multiplication exceeds the death rate in a given organ, that organ grows. When the two processes are in a state of equilibrium, the organ or tissue remains stationary in bulk. When disintegration of cells exceeds multiplication, the organ deteriorates and finally dies, and when decay or atrophy proceeds far enough in any essential organ, somatic death ensues.

Death from old age is the natural result of the loss of the power of the body cells to multiply themselves, although for some time after multiplication ceases life may be sustained while the last-produced cells are capable of functioning; on the other hand, somatic death may precede the cessation of cell multiplication if, for any reason, the cells produced are incapable of performing their proper functions.

Cell multiplication takes place in two ways; by **amitotic** and by **mitotic** division of pre-existing cells.

Amitotic Division.

This is more simple than mitotic division. First, the nucleus is constricted and divided, then the cell body is similarly constricted and divided, and two daughter cells are formed, each half the size of the mother cell. The laws which govern the process of amitotic division at some periods of growth and require amitotic division at other periods are not yet known.

Mitotic Division.

Mitosis, or karyokinesis, is the more important form of cell division. It is that which occurs during all rapid growth of tissues, especially in the embryo and the foetus. There are two forms of mitosis, homotype and heterotype. The former is much more

common, while heterotype mitosis occurs in one of the two cell divisions which happen during the maturation of the germ cells and during some of the cell divisions which take place in the production of malignant tumors.

Homotype Mitosis. There are four phases of homotype mitosis; the **prophase,** the **metaphase,** the **anaphase,** and the **telephase.**

During the **prophase** transformations occur in the centrosome and the nucleus. The centrosome and its centriole divide into two parts, one of which moves to one pole of the cell and the other to the opposite pole. In the nucleus, the nucleolus disappears either by passing into the cytoplasm where it disintegrates, or by other means unknown. The chromatin substance is gathered into a thread, at first slender and afterward thicker. At the same time a spindle of achromatin fibrils appears between the two daughter centrosomes and the nuclear membrane disappears.

As soon as the **achromatic spindle** is completed the chromatin thread breaks up into a number of segments, the chromosomes, which arrange themselves around the equator of the achromatic spindle. It is believed that each chromosome contains elements derived partly from the maternal and partly from the paternal ancester of the cell. Each chromosome becomes closely attached to one of the fibrils of the achromatic spindle.

Winiwarter declares the number of chromosomes in each occyte I (see page 218) as 48, and in each spermatocyte I 47. Each mature ovum, therefore, has 24 chromosomes but some spermatids (page 220) have 23 and 24. The union of a spermatozoon having 24 chromosomes with a mature ovum produces a female, while that of a spermatozoon having 23 chromosomes is said to produce a male.

At the end of the prophase the nucleus and nucleolus have entirely disappeared and in their stead the cell body contains two centrosomes, an achromatic spindle, and the chromosomes. The chromosomes are grouped around the center of the achromatic spindle and the two centrosomes lie at the opposite poles of the achromatic spindle.

The **Metaphase.** Each chromosome divides into two equal parts, the rods or loops splitting longitudinally; the division always commences at the point where the chromosome is in relation with the achromatic spindle.

The **Anaphase.** In the anaphase the halves of the chromosomes thus divided move toward the opposite poles of the achro-

matic spindle and when they move as far as the daughter centrosomes the anaphase ends and the telephase begins.

The **Telephase.** A constriction appears around the center of the cell. It deepens until the cell is divided into two halves through the equator of the achromatic spindle. Each resultant daughter cell contains the typical number of chromosomes and a portion of the achromatic spindle.

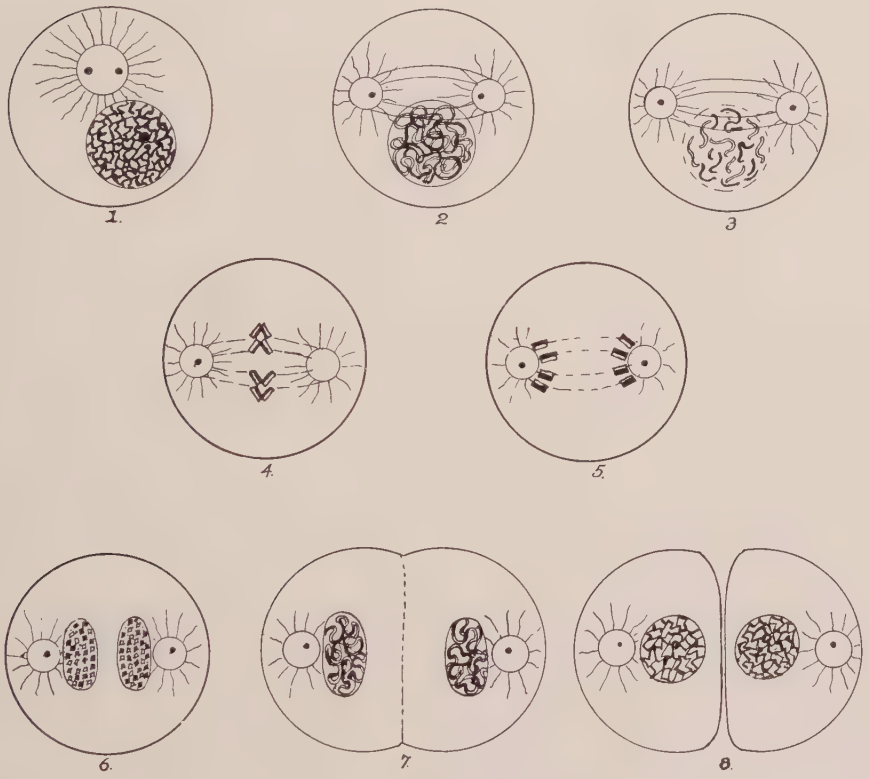

Fig. 81. Mitotic Cell Division

The **Resting Stage.** Actual division being complete, the new cell undergoes a period of rearrangement of its contents, known as the resting stage. During this period a nucleus is formed in each cell by the appearance of a nuclear membrane around the chromosomes, which pass in reverse order through the stages of change they have undergone. A nucleolus reappears. The cell increases in size.

Limitation of Cell Life. Cell division is not unlimited. In some cases the ancestors of certain tissue cells have been capable of producing only a limited number of descendents, which grow up, func-

tion for a fixed period, and then disintegrate; in other cases the descendent cells seem to possess unlimited power of reproducing themselves but the more remote becomes the descent the less able are the resulting cells to perform their functions. In either case the ultimate result is death.

Heterotype Mitosis. The chief difference between homotype and heterotype mitosis is that in the former each daughter cell contains the same number and kind of chromosomes as the mother cell, while in heterotype mitosis the number of chromosomes is reduced to half. In this type, each chromosome is really a twin chromosome in that it is formed of two chromatin segments lying side by side.

A cell containing half the number of chromosomes of its mother cell can divide once, hence from each original cell four granddaughter cells may be produced. Whether such cells can again subdivide, or can continue to live and function is unknown. The chief end of such cells appears to be to unite each with another cell containing half the typical number of chromosomes to produce a new cell which contains the full number of chromosomes and also possesses the full power of reproducing itself by division.

The Gametes.

The gametes are the germ elements by the union of which, in pairs, new animals are produced. The female gametes are called **ova** and the male gametes **spermatozoa.** Each is produced by heterotype mitosis and is useless and transitory except when united with the complementary gamete. The gametes are specially modified cells by means of which hereditary characteristics are transmitted from generation to generation. They are derived from **primitive germ cells** which are developed in the special sex glands, the ova in the ovaries of the female, and the spermatozoa in the testes of the male.

The descendents of the primitive germ cells increase in number by mitotic division until they reach a number which is probably fixed and exact. They then begin to increase in size and the female cells are then called **oocytes of the first order** (*oocytes 1*) while the male cells are called spermatocytes I. Both possess all the essential parts of a typical cell and each has special pecularities which differentiate it from other cells. Each is capable of producing just four descendents; the process of producing these descendents is called the **maturation divisions;** by these divisions the oocyte I gives

rise to one **mature ovum** and three small impotent cells, the **polar bodies,** while the spermatocyte I gives origin to four equal spermatids.

The Ovum. The ovum is peculiar among cells for its large size, its large nucleus, and its definite investing membrane, the oolemma; otherwise, it presents all the characteristics of a typical cell. The ova are formed within the ovary, where the young ova are surrounded each by a single layer of cells, the **stratum granulosum;** this layer, with the oocyte I, is called a **primary ovarian follicle** (*O. T. Graafian follicle*). The cells of the stratum granulosum multiply rapidly and speedily become a layer several cells in thickness. Meanwhile the ovum becomes surrounded by its membrane, the oolemma.

A fluid-filled cavity appears in the stratum granulosum and the whole structure is then called a **vesicular ovarian follicle.** The cavity increases in size and separates the larger part of the oocyte from contact with the stratum granulosum. At full maturity the ovum measures 200 microns in diameter. It is a cell body with a limiting membrane and containing a large nucleus, a centrosome, mitochondria, and numerous deutoplasmic or yolk granules. The deutoplasmic granules, far less numerous in the human ovum than in those of most lower forms of life, are believed to be made up of nutritive material for the use of the zygote.

Maturation of the Ovum. The ovum is matured by two divisions, the first heterotypic and the second homotypic mitosis, which result in the formation of four daughter cells, one of which is a complete, functioning ovum and the other three useless polar bodies. The first maturation division separates the oocyte I into an **oocyte II** and a **first polar body,** each containing half the typical number of chromosomes. During the second maturation division, each of these separates into two. The second division follows the first without a resting stage, so that no nucleus is formed in the oocyte II. Each descendent of the oocyte I contains half the typical number of chromosomes, and those of the mature ovum quickly become enclosed within a new nucleus, the female pronucleus. The mature ovum thus differs from a typical animal cell in that it contains only half the typical number of chromosomes and probably no centrosome.

The first maturation division takes place in the ovary; the second takes place only after the spermatozoon has entered the oocyte, which is usually in the upper or middle part of the uterine tube. If a spermatozoon does not reach and enter the ovum, the latter passes off through the genital tube or is there disintegrated; if union of the two sex cells occurs, the result is the formation of a **zygote,** from which a new individual may develop; in that case the polar bodies persist until the zygote has divided once or twice, then disappear.

Fig. 82. Mature Ovum.

Spermatocytes. The male germ cells which correspond with the oocytes I are called **spermatocytes I,** or spermatocytes of the first order. They lie in the walls of the tubules of the testes, or male sex glands, and their descendents become spermatozoa. Each spermatocyte I produces only four descendents by two successive divisions, the first heterotypical and producing two cells, each with half the typical number of chromosomes, and the second homotypical. The cells produced by the first division are called spermatocytes II and the four resulting from the second division are spermatids.

The two daughter cells of the spermatocyte I are called spermatocytes II; the four cells resulting from the second maturation division are called **spermatids.** They differ from the typical animal cell in that each possesses but half the typical number of chromosomes and in that each possesses an accessory body and two centrosomes. Unlike the ovum, which after the second maturation division, is ready for conjugation with the male cell, the spermatid has yet to undergo a complicated transformation before it becomes a spermatozoon. It also differs in that all the four spermatids are of equal size and potency.

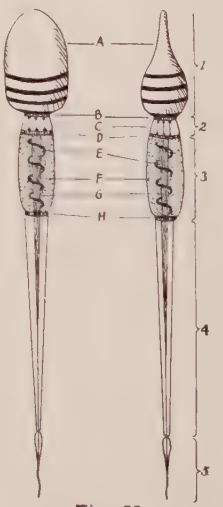

Fig. 83. Spermatozoon. A, Head-Cap; B, Centrosome; C, Neck; D, Centrosome; E, Spiral Sheath; F, Axial Filament; G, End Ring; H, 1, Head; 2, Neck, 3, Body; 4, Tail; 5, End Piece.

The Spermatozoon. A spermatozoon, developed from a spermatid, is an elongated structure about 50 microns in length. It has a head, a neck, a body, a tail, and an end-piece. The

head, about 4.5 microns in length, is laterally compressed and ovoid; it is shaped somewhat like a spearhead. It is joined to the body by a short constricted neck. Where head and neck join is located the **anterior centrosome** and where neck and body join is the **posterior centrosome,** from which a thread-like **axial filament** extends throughout the length of the body and into the tail.

The process by which a spermatid develops into a spermatozoon is somewhat obscure and it will serve no purpose to go into its details here. It is important to note, however, that the nucleus of the spermatid becomes the head of the spermatozoon.

Fertilization.

When the male and female gametes meet, usually in the upper or middle part of the uterine tube, a process takes place which is called fertilization and by which the union of the two becomes a cell containing the full number of chromosomes and capable of developing into a zygote.

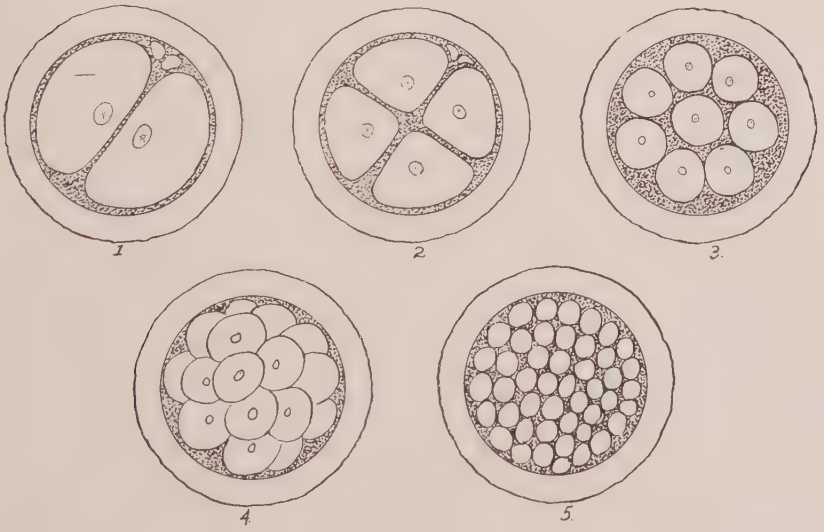

Fig. 84. First Stages of Segmentation of Mammalian Ovum.

It is supposed that the process of fertilization in humans is similar to that in animals. In the latter, as the male gamete approaches the ovum there appears on the latter a small bulging prominence called the **cone of attraction.** The spermatozoon penetrates the oolemma, head first, at the cone of attraction and passes into the body of the ovum. Thereafter occurs a reorganization

of the contents of the two cells, the one within the other, by which they become one cell with the full number of chromosomes, half contributed by the male gamete and half by the female. This is the beginning of the **zygote.**

Segmentation of the Zygote.

Immediately after the formation of the zygote begins a series of mitotic divisions; a splitting into two, then four, then eight cells, etc. The rapidity of this multiplication is amazing. At first the cells resulting from these divisions seem equal in structure and capabilities, but very soon their descendents begin to evidence differentiation which will continue until the foundation for the varied organs and tissues of the body has been laid. It is at this time that certain cells are set aside, as it were, as germinal cells, possessing in full the capabilities of their ancestors and destined to become the progenitors of the next generation. The remaining groups of cells, while assuming gradually the special characteristics necessary for the formation of some particular organ or tissue and the performance of some special function in the body economy, possess only a limited power of reproducing themselves and will eventually be used up in the life of the individual which is being constructed.

As cell division progresses a mulberry-like mass is formed called a **morula.** When this is established, the first definite change which appears is the differentiation of the cells into an outer and an inner mass; the outer is the **trophoblast,** which plays an important part in the nutrition of the embryo and foetus. It helps to form the **chorion,** the outermost envelope covering the zygote, which is subsequently divided into a placental and non-placental portion. The inner group of cells divides into three groups; the **ecto-mesoderm,** the **primary mesoderm,** and the **entoderm.**

In animals a cavity appears in the zygote and enlarges until it divides the inner mass from the outer layer except at one pole, where they remain in contact. In humans the place of this cavity is taken by a jelly-like substance. At the same time the ecto-mesodermal and entodermal segments become hollowed in their interiors into vesicles.

At this time the zygote consists of three vesicles or spheres. The larger sphere is bounded by the trophoblast and contains the other two; the larger of the two contained is the ecto-mesodermal vesicle, the smaller the entodermal vesicle.

The Embryonic Area.

That section of the zygote in which the two vesicles lie in contact with each other is the area from which the embryo will be formed. The embryonic area is at first circular in outline. As it grows, the area becomes oval and a **primitive streak** appears on that part of the oval which becomes the posterior area. The primitive streak is a thickened ridge of cells which grows from the ecto-mesoderm in the posterior part of the embryonic area; its lower cells, those next the entoderm, are mesodermic cells, and by multiplying they give rise to much of the embryonic mesoderm and to an organ called the **notochord.**

EMBRYOLOGY OF THE NERVE SYSTEM

Immediately following the formation of the primitive streak a furrow, the **neural groove,** appears in the anterior part of the embryonic area. This groove longitudinally troughs a thickened layer of rapidly proliferating ectodermal cells known as the **neural plate,** which contains the beginnings of the entire nervous system with the exception of the end-organs of certain sensory cranial nerves, such as the olfactory; from it also are derived the cells of the sheaths of the nerve fibres, and the chromaffin cells of the suprarenal glands and other chromaffin bodies. The lateral walls of the neural groove are named the **neural folds.**

The Neural Tube.

At first the lateral edges of the neural plate are ill-defined and blend smoothly into the surrounding tissue; shortly, however, the edges rise, pushed up by the subjacent mesoderm, and the groove appears. The anterior ends of the neural folds meet in the mid-line; the posterior ends embrace the anterior end of the primitive streak and later unite to cut off part of the streak, that part from which a canal opens into the entoderm. This canal remains for a time as an opening between the neural canal and the cavity around which the intestines will be developed, and is called the **neurenteric canal;** it is a transitory passageway.

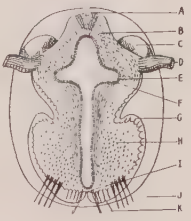

Fig. 85.

Section Through Spinal Cord of Human Embryo at 4½ Weeks.

A, Roof Plate; B, Alar Lamina; C, Oval Bundle; D, Posterior Root; E, Ependymal Layer; F, Central Canal; G, Lateral Funiculus; H, Basal Lamina; I, Floor Plate; J, Anterior Root; K, Anterior Funiculus.

The neural folds develop rapidly so that the neural groove appears to deepen; the walls bulge inward, touch, and fuse, making of the canal a **neural tube,** closed except at its extremities where

there are small openings, the **anterior** and **posterior neuropores.** The neural tube presents a ventral wall or **basal lamina,** two lateral walls, and a dorsal wall or **alar lamina;** the tube will persist as the central canal of the spinal cord and the ventricular system in the brain.

Fusion of the lateral walls of the neural groove to form a tube begins in the cervical region and extends headward and feetward. In the third week of foetal life the fusion is completed by the closure of the anterior and posterior neuropores. During the rise which accompanies the fusion of the walls, the neural folds carry with them the adjacent ectoderm, so that when the tube is completed it lies embedded in the embryo and separated from the surface by a layer of ectoderm, except that it is attached for a time to the superficial ectoderm by a ridge of cells known as the **neural crest.**

The walls of the neural tube give origin to the central nervous system, the retinae, and the optic nerves. The neural crest gives origin to the cerebral and spinal nerve ganglia, the sympathetic ganglia, the chromaffin elements of the chromaffin organs, and the sheaths of the peripheral nerves. For a time during this stage of development the entire nervous system is manifestly one system; a distinction between central and peripheral, cerebrospinal and sympathetic portions, does not exist. The entire primary co-ordinating mechanism which is to dominate the development of the embryo and foetus and govern the functional relations of the organs and tissue of the matured body, is here first congregated in one mass; it is significant also that essential parts of many of the endocrinous glands which, when developed, will constitute a secondary and subordinate co-ordinating mechanism for the government of bodily functions, also originate in the neural crest in close relation with the true nerve elements, which they resemble.

Formation of Ganglia.

The ganglia first appear as cell buds or clusters, which project in a double chain from the neural crest. These presently become detached from the neural tube and the crest disappears. There then begins a migration, a movement of these cell groups ventralward along the sides of the neural tube.

When the migration has reached the level of the anterior margin of the neural tube, a part of each cluster ceases to migrate and remains at the side of the tube to form the cerebral and spinal nerve ganglia. Another portion of each cluster continues its migra-

tion ventralward to the situation it will occupy as a ganglion of the great gangliated cord of the sympathetic. From this situation another portion breaks off and continues to travel into one of the body cavities. Some of these groups finally become ganglia of the cardiac, coeliac, and hypogastric plexuses; some continue beyond these plexuses into the walls of peripheral organs which they are to innervate; other cell groups from these ganglia become the chromaffin bodies. From the primitive ganglia the sheaths of the peripheral nerves are also developed.

Formation of Sympathetic.

While embryologists usually describe the sympathetic ganglia as having been derived from the neural crest by ventralward migrations, there are contradictory arguments on the subject. It is pointed out that the chief elements of the sympathetic system are motor rather than sensory and remain connected with the motor area of the cord rather than the sensory. It is asserted that the cells of the sympathetic ganglia are originally found in the basal portion of the wall of the neural tube; that they send forth processes which establish connections with the rudiments of the viscera and glands; and that as the structures grow and move outward away from the central axis the nerve cells follow them, retaining their connection with the central axis by means of gradually elongating fibres.

In some instances the cells are drawn out for a comparatively short distance and become the ganglia of the great gangliated cord; in others, the cells retain a close proximity to the organs they supply and therefore follow these organs for great distances to become the ganglia of the cardiac, coeliac, and hypogastric plexuses and the more remote collateral ganglia.

Of the two views; i. e., that the sympathetic ganglia are derived from the neural crest and that they develop from the wall of the neural tube, this writer inclines toward the latter, in the absence of positive proof and because of the otherwise perfect arrangement of the primitive sensory and motor nerve matter into a dorsal and a ventral layer. The motor cells of the sympathetic probably migrate along motor nerves rather than sensory; the sensory elements of the sympathetic, relatively few in number, probably originate in the neural crest and separate themselves from the rudimentary spinal ganglia.

During this process of cell migration by which the different ganglia assume positions approximating those which they will ultimately occupy, each cell projects from its substance more or less elongated processes. From the central ends of the ganglia the processes enter the walls of the neural tube and establish connections there; from the peripheral end the processes extend to varying distances to establish relations with the cell groups which are the progenitors of the various body organs. At the same time the cells in the wall of the neural tube are projecting similar processes which will become the ventral root fibres of the spinal and cranial nerves and these fibres come into relation with fibres from the spinal and cerebral ganglia to form mixed nerves.

The formation of the elements of the spinal nerves is remarkably regular; one sympathetic ganglion is formed to correspond with

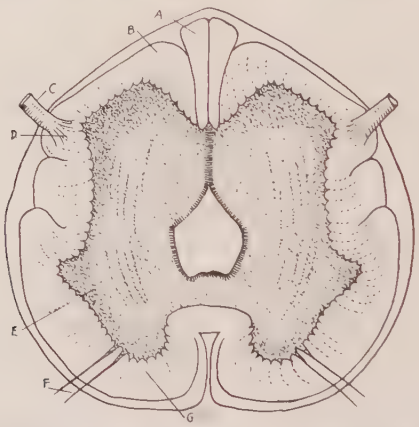

Fig. 86. Section Through Spinal Cord of Embryo at 3 Months. A, Fasciculus Gracilis; B, Fasciculus Cuneatus; C, Posterior Nerve Root; D, Lateral Funiculus; E, Anterior Column (Gray Matter); F, Anterior Nerve Root; G, Anterior Funiculus.

each spinal nerve, although several ganglia may coalesce, in such case maintaining connection with the several corresponding spinal nerves. Each spinal nerve is mixed, that is, composed of motor elements from the wall of the neural tube and sensory elements derived from a ganglion. In the cerebral region, however, there is much less regularity of formation; some of the nerves are unmixed; i. e., are derived wholly either from the basal lamina or the alar. Instead of a single ganglion for each sensory nerve there may be two, formed by a separation during the period of migration. The development of the nervous system is seen in its simplest form around that part of the neural tube from which the spinal cord and spinal nerves are formed; the changes which take place around

the cephalic end of the tube are so much more complicated that the exact plan of development cannot always be followed.

The Brain Vesicles.

Even before the conversion of the neural groove into a closed tube is completed, the anterior end undergoes an expansion which indicates the division between cephalic and spinal portions, the dilated portion being the rudiment of the brain and the undilated portion the rudiment of the spinal medulla. Three secondary dilations of the tube at its cephalic end indicate the division of the cephalic portion into three parts; the primitive **fore-brain, mid-brain, and hind-brain.** Before the closing of the tube there appears an evagination of each lateral wall of the primitive fore-brain, called the **optic vesicle,** from which will be developed the retina, the optic nerves, the posterior epithelium of the ciliary body, and the iris. The optic vesicle becomes the **optic stalk** by a forward projection, and contains at its anterior end the nerve elements for the above named structures; as the stalk lengthens, the nerve cells for the retina give off centrally directed processes which maintain a connection with the fore-brain and become the optic nerves and optic tracts.

The three primary brain vesicles remain connected with each other and the cavity of the hind-brain remains continuous with the spinal portion of the tube, which will become the central canal of the medulla spinalis. Each brain vesicle, however, has its own walls.

After the formation of the vesicles a diverticulum grows out from the primitive fore-brain which will finally divide into two considerable cavities, the lateral ventricles, and the walls of which will attain a growth far overshadowing that of the other walls. This diverticulum becomes the cavity of the **secondary fore-brain,** or cerebral hemispheres. The hemispheres grow rapidly and soon overlap the rest of the fore-brain, the mid-brain, and eventually the hind-brain. From the cephalic end of each is given off a secondary diverticulum, the **olfactory diverticulum,** which later becomes converted into the olfactory bulb and olfactory tract.

When first formed, the cerebral hemispheres are united across the median line by a plate called the **lamina terminalis.** This persists through life but later the connection is made more complete by the development of three secondary commissures; the corpus

callosum and fornix, which grow across the space between the hemispheres and unite their medial walls, and the anterior commissure, which grows through the lamina terminalis and unites the two temporal lobes.

Differentiation of the Walls. In the later stages of development the wall of the primitive hind-brain, or rhombencephalon, becomes separated into two parts; the **medulla oblongata,** the feetward portion, continuous with the medulla spinalis, and a more cephalic portion which is continuous with the medulla oblongata on the one hand and with the mid-brain on the other. The ventral wall of this cephalic portion ultimately becomes the **pons;** the dorsal wall expands into two parts, one of which becomes the **cerebellum** and the other the **anterior medullary velum** and the **brachia conjunctiva.**

The wall of the mid-brain vesicle gives origin, by its ventral portion, to the **cerebral peduncles** while from its dorsal part grow the **corpora quadrigemina.**

It will be necessary in stating the changes which take place in the walls of the primitive fore-brain vesicle, to consider the ventral, lateral, and dorsal walls separately.

The secondary fore-brain, already mentioned, is formed by an extension of the anterior part of the fore-brain vesicle and becomes the two **cerebral hemispheres,** constituting the **telencephalon.** After the rudiments of the telencephalon are developed, the remainder of the primitive fore-brain, with the undivided stalks of the secondary fore-brain diverticulum, become the **diencephalon.** The cephalic end of the diencephalon is closed by the lamina terminalis, from which run dorsolaterally the **columns of the fornix.** In association with the lamina terminalis are also developed two commissures, the anterior commissure, which connects the two cerebral hemispheres, and the optic chiasma, in which the medial fibres of the optic nerves decussate.

From the anterior end of the ventral wall of the diencephalon projects a diverticulum toward the dorsal wall of the primitive mouth cavity; the walls of this diverticulum develop the posterior lobe of the **hypophysis** (*O. T. pituitary body*), the infundibulum, and the tuber cinereum. Caudal to the hypophyseal diverticulum appears an elevation on the wall of the diencephalon from which are formed the **corpora mammillaria.**

The **posterior perforated substance** develops partly from the ventral wall of the diencephalon and partly from the anterior, or cephalic, end of the mid-brain wall.

The greater part of the dorsal wall of the diencephalon is thinned to a single epithelial layer, but from near its feetward end a diverticulum is projected dorsally which becomes the **epiphysis,** or **pineal body.**

Each lateral wall of the diencephalon is differentiated into a dorsal and a ventral portion. The dorsal part forms the **optic thalamus,** and the **medial** and **lateral geniculate bodies,** on the posterior end of the thalamus. The ventral part of the lateral wall develops the **hypothalamus** of the adult brain.

Development of Spinal Cord. During the first three months of intra-uterine life the spinal portion of the neural tube develops

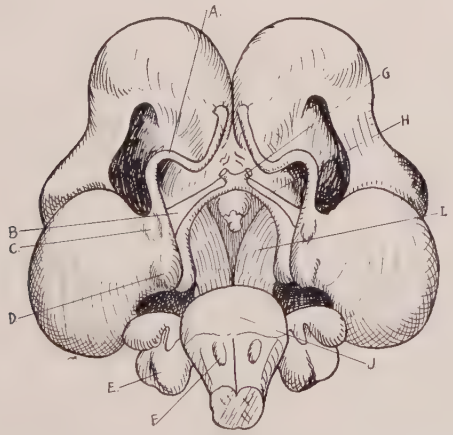

Fig. 87. Interior View of Brain of Four-Month Foetus. A, Olfactory Gyrus; B, Gyrus Diagonalis; C, Gyrus Albiens; D, Gyrus Semilunaris; E, Cerebellum; F, Olive; G, Optic Chiasma; H, Optic Tract; I, Cerebral Peduncle; J, Pons.

equally throughout its extent, but thereafter the longer cephalic portion continues to develop into the medulla spinalis, while the feetward portion deteriorates and ultimately becomes the thread-like **filum terminale.**

The walls of the spinal portion of the neural tube in the early stages of development consist of a mass of nucleated protoplasm more or less arranged in longitudinal cell columns. An external limiting membrane surrounds the entire tube and an internal limiting membrane surrounds the neural canal. The lumen of the canal at this time is somewhat ovoid; it is bounded by ventral, dorsal, and lateral walls.

In the lateral wall many of the cells assume a spherical form and become the **germinal cells** from which are developed all the **neuroblasts,** which will be transformed into adult nerve cells, and in some cases **spongioblasts,** predecessors of the reticular sustentacular tissue of the central nervous system; most of the spongioblasts are very early differentiated from the ancestors of the neuroblasts.

As the process of cell differentiation advances there develop three distinct layers in the wall of the tube; (a) an inner layer of columnar epithelium surrounding the central canal; (b) an intermediate mantle layer made up of neuroblasts and their processes, the nerve fibres, with some spongioblasts; and (c) an outer reticular layer. The mantle layer becomes converted into the gray matter of the central nervous system.

The peripheral layer becomes the white matter of the cord as it is permeated by fibres which are the processes of cells of the mantle layer, of the spinal ganglia, or of cell groups in the cerebrum. In the brain the formation of white matter takes place in a similar way by the transformation of the reticular layer, and also internal to the gray matter by fibres which insert themselves between the mantle layer and the central ependyma.

As differentation of the cells of the wall of the neural tube proceeds, each lateral wall is divided by a dilatation of the central canal called the **sulcus limitans,** into a ventral division, the **basal lamina,** and a dorsal, the **alar lamina.**

Formation of Canals and Ventricles.

The ultimate state of the neural tube is a canal system extending throughout most of the central nerve system. It will be remembered that the anterior, or cephalic end of the tube expanded into a diverticulum, most of which later divided into two lateral cavities. These cavities of the telencephalic portion of the secondary forebrain become the highly irregular **lateral ventricles** of the cerebral hemispheres; the undivided portion of that dilatation becomes the **third ventricle** and remains in communication with the lateral ventricles by small apertures, the **interventricular foramina** (*O. T. foramina of Monro*). The cavity of the hind-brain becomes the **fourth ventricle,** connected with the third ventricle by the **cerebral aqueduct** (*O.T. aqueduct of Sylvius*) and continuous at its feetward angle with the central canal of the cord, which is the remnant of

the spinal portion of the primitive neural tube. Communication between this ventricular system and the space surrounding the cord is lost for a time but is eventually re-established by the perforation of the thin covering of the fourth ventricle to form three small orifices, one median and two lateral.

The three membranes which surround the cord and brain are formed by a modification of the mesoderm. The inner layer, the **pia mater,** closely invests the cord and brain; between it and the **arachnoid,** and between the latter and the **dura mater,** spaces are formed.

The Internal Ear.

The cochlea and vestibule are formed chiefly from the **otic vesicle,** formed of ectodermal epithelium, and projected from the lateral surface of the head of the embryo at the level of the hindbrain. Its association with the development of the brain is at all times intimate.

Time of Development.

The first fourteen days after the fertilization of the ovum is the period of the zygote, during which the rapidly multiplying cells remain relatively undifferentiated. At that time the zygote descends the uterine tube and enters the uterus. It is not until the beginning of the third week that a definite embryonic area appears; by the eighteenth or nineteenth day the neural groove is faintly indicated. During the ensuing twenty-four hours the embryo grows with great rapidity and the head fold begins to form.

By the middle of the third week the neural folds are well developed and in the next three days the neural tube is enclosed except at its cephalic and caudal ends; the cervical flexure is begun. At the end of the first month the otic vesicles have appeared. In the latter part of the fourth or the beginning of the fifth week the cephalic flexure turns the anterior part of the brain tailward. During the fifth week the lens of the eye appears, becomes a vesicle, and separates from the surface. In this week the head grows so rapidly as to assume preponderant size as compared with the body; the brain far outgrows the remainder of the nervous system in bulk. In the fifth week also the olfactory pits appear.

Period of Medullation.

The white matter of the brain and medulla spinalis is largely composed of medullated nerve fibres; i. e. those possessing a myelin

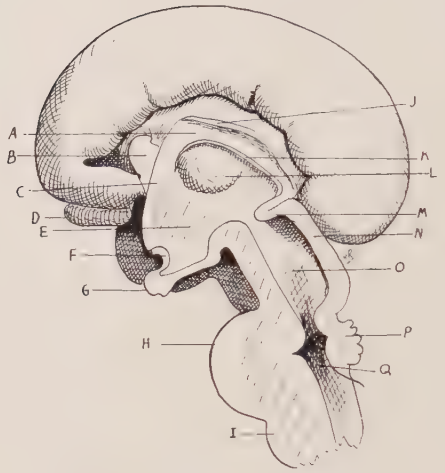

Fig. 88. Drawing of Median Sagittal Section of Embryo Brain at Four Months.
A, Choroid Fissure; B, Corpus Callosum; C, Ventral Commissure; D, Rhinencephalon; E, Third Ventricle; F, Optic Chiasma; G, Hypophysis; H, Pons; I, Medulla; J, Gyrus Dentatus; K, Taenia Thalami; L, Thalamus; M, Posterior Commissure; N, Colliculi; O, Cerebral Aqueduct; P, Cerebellum; Q, Fourth Ventricle.

sheath. These sheaths are not developed simultaneously with the axons themselves but at a later period; not until the myelin sheath of an axon is complete can that axon perform its characteristic function. In the case of the axons which make up the tracts of the cerebrospinal axis, medullation does not begin until the fifth month of foetal life; it then proceeds, not simultaneously in all tracts, but at varying rates.

The fibres which are first to receive their myelin sheaths are those which serve to bring the central nervous system into relation with the peripheral organs; that is, the peripheral sensory and motor neurons; next those intrinsic tracts which unite different levels of the central nervous system; then the tracts, both ascending and descending, which connect the medulla spinalis and the cerebellum; and lastly, the afferent and efferent cerebrospinal tracts. The cerebrospinal tracts, along which travel the impulses which control voluntary motion, do not complete their medullation in the human until some time after birth.

In general, medullation seems to keep pace with functional needs; thus, in young animals, the cerebrospinal tracts are covered much more rapidly than in the human and we witness the spectacle of the young animal performing the functions of locomotion and prehension at an age when the human infant is entirely helpless. Animals born with closed and covered eyes show a slower

myelinization of optic nerve fibres than those whose eyes are immediately open. In animal experimentation, it is reported that if light is admitted to one eye of such an animal and excluded from the other, the optic nerve fibres of the one eye will complete their medullation much the earlier.

It is to be remembered that the nerve apparatus controlling the involuntary (*vegetative*) functions, and therefore necessary from the beginning of post-natal life, do not require medullation, and that those neurons which link the cerebrospinal system to the sympathetic are among the first myelinized and thus fully ready for service some time before birth.

PHYSIOLOGY
OF THE
NERVOUS SYSTEM

PART I

General Physiology of Nerve Tissue

The tissues of which the body is composed are: connective, muscular, epithelial, and nervous tissue, and blood. Of these, the nerve tissue is most important, because it unites the other organs and tissues and co-ordinates their functional activities, and brings the individual into relation with the outside world. It is the most delicate and sensitive of all tissues and is the one through which life primarily expresses itself.

The nerve tissue, as a whole, is arranged in a complicated system, which is divided for convenience in study into two major parts, the **encephalospinal** (*cerebrospinal*) system and the **sympathetic** (*vegetative*) system. The earlier concept that there are two distinct nerve systems is obsolete; it is now known that all parts of the nerve system develop from the same embryonic cell group, that all nerves have similar properties and functions, and that each part remains closely linked with the others.

The **encephalospinal system** (*or division*) is made up of the encephalon (*brain*) and the medulla spinalis (*spinal cord*), contained respectively within the cranial and spinal cavities, and the cranial and spinal nerves, attached to the encephalon and spinal medulla and numbering respectively 12 pairs and 31 pairs.

The **sympathetic system** is made up of:

(a) The gangliated cord, a double chain of ganglia, extending from the base of the skull to the tip of the coccyx on either side of the vertebral column.

(b) Various groups of ganglia situated in the head, face, thorax, abdomen, and pelvis.

(c) An extensive and intricate system of communicating nerves which unite these ganglia with each other, with peripheral organs, and with the cerebrospinal system.

The Neuron.

All the organs of the nerve system are made up of individual nerve cells called neurons. The neurons, although having a common embryonic origin, are biologically distinct from one another. Since the neuron is the morphologic unit it follows that it is also the functional unit of the nerve system; the special functions found to belong to organs of the nerve system are the accomplishments of the aggregations of neurons of which the organs are composed.

The neuron is a cell, made up of a cell body and its processes; these processes are (a) an axon; (b) the end tufts or terminal processes; and (c) the dendrites. It is most convenient to describe the cell body, the dendrites, and the axon separately, although it must not be forgotten that they are parts of the same cell unit. Neurons differ widely in the size and shape of their cell bodies, and in the number and length of their processes. The term dendrite is applied to those processes which carry stimuli toward the cell body; the term axon to that process which carries impulses away from the cell body. In other words, the dendrite is invariably cellulipetal in function, the axon invariably cellulifugal. Some writers differ from this interpretation and apply the term axon to any elongated process of a nerve cell, which extends for a great distance from its origin, especially to any long medullated nerve fibre. This use of the words leads to confusion, inasmuch as axons may vary in length from a few millimeters to a full meter.

The Nerve Cell.

The nerve cell, or body of the neuron, varies greatly in size and shape in different parts of the body. In their original embryonic form they are ovoid, almost spherical, in shape but in the course of development and functional differentiation they take on various characteristic forms, such as pear-shaped, stellate, pyramidal, fusiform, etc. The smallest nerve cells have a diameter of not more than 1/3,000th of an inch and the largest about 1/400th. Each cell is made up of a granular, striated, protoplasm called neuroplasm, which is composed of a firmer spongioplasm known as the **neuroreticulum,** and a more fluid substance, sometimes called **neurolymph.** Each cell has a distinct vesicular nucleus and a nucleolus. No special cell membrane is discoverable.

The neuroreticulum is made up of delicate, thread-like condensations of the protoplasm, which interlace in a complicated manner. It is held by some observers that these **neurofibrils** are the special

pathways for the transmission of stimuli through the nerve cell and that they extend throughout the axon, as elongated continuations of the network of the cell. They are said to be the real conductors of nerve energy, but as yet the evidence seems insufficient to warrant acceptance of this view as anything more than a hypothesis.

The adult nerve cell projects from its surface processes of various lengths which divide and subdivide rapidly, and near their terminations develop lateral buds, or **gemmules,** which give to them a feathery appearance and accommodate themselves readily to the work of gathering stimuli from the end-tufts of other neurons. These receptive processes, in their entirety, are the **dendrites.** The ultimate branches of the dendrites never truly anastamose with each other or with the terminals of other neurons. Their communication is altogether by contact. Dendrites are usually short, in comparison with axons, and are distributed in the vicinity of the cell body, which they may almost embrace; some, however, are much elongated, enveloped in medullary sheaths, and take on the characteristic appearance of axons.

The **axon** arises from a conical projection on the surface of the nerve cell and is usually the first process to grow out from the cell. It speedily exhibits marked differences from the dendrites. It usually has a uniform diameter throughout its length, is distinct and regular in outline, and has a hyaline appearance. Axons vary greatly in length and the longer frequently give off, especially in the brain and medulla spinalis, laterally directed branches called **collaterals,** each of which possesses all the capabilities of the parent axon. The axon does not diminish in thickness by the giving off of collaterals.

Structurally, the axon appears to be composed of a clear, fluid protoplasm in which are contained fine, dark-colored, longitudinal fibrillae, the neurofibrils.

Almost all axons are invested by a thin, tough, tubular membrane called the **neurilemma;** some axons within the central nerve system are, however, devoid of neurilemma. In addition, many axons are further invested with a **medullary sheath, or myelin sheath,** (*sheath of Schwann*). The medullary sheath, when present, lies within the neurilemma and surrounds the axon. It is composed of a clear, semifluid, homogeneous, fatty substance which, when treated with reagents, becomes opaque and gives a whitish appearance to the nerve fibre. Most of the peripheral cerebrospinal

nerve fibres are medullated; those of the sympathetic are usually non-medullated, but possess a neurilemma; within the brain and medulla spinalis are many of both varities of fibres, medullated and non-medullated.

The **end tufts,** or terminal organs, are formed by a subdivision of the axon which takes place near its termination; it may split into a number of parts, each independent of the others and all free from medullation. This seems to be a device which serves to bring a single axon into communication with a number of tissue cells at once. In the brain and medulla spinalis a similar breaking-up of the axon enables it to communicate at once with the dendrites of several neurons.

Nerve Fibres.

The term "nerve fibre" is applied to the long process of a nerve cell, whether it be axon or dendrite, together with its investing sheaths. Nerve fibres are divided into two groups, medullated (*myelinic*) and non-medullated (*amyelinic*) according as they do or do not possess myelin sheaths.

Medullated Nerve Fibres.

A medullated nerve fibre consists, from without inward, of (a) the neurilemma; (b) the myelin sheath; and (c) the axon (*axis cylinder*).

The **neurilemma** is a tubular sheath, thin and transparent, but quite tough and elastic. It adheres closely to the medulla, or myelin. It is believed to be a protective covering for its contents.

The **myelin sheath, medulla,** or **white substance of Schwann,** surrounds the axon and fills the neurilemma. It is a clear, semi-fluid substance, which becomes opaque and whitish when treated with reagents. Its function is not fully understood, but the fact that the projection fibres in the cerebrospinal axis do not assume their function until medullated, and the further fact that the various groups of fibres develop myelin in the order in which their functional activity is required by the body, would suggest that the myelin sheaths may act as a sort of insulation, preventing distribution of nerve impulses except at the end contacts of neurons. Against this view is the fact that many fibres, such as those of the sympathetic system, remain unmedullated, yet function without apparent lateral conduction of impulses.

At intervals of about seventy-five times the diameter of the medullated nerve fibre appear constrictions, which interrupt the myelin sheath and at which the neurilemma dips down to reach the surface of the axon. These constrictions are called the **nodes of Ranvier,** and are believed to be the means by which a free interchange of nutritive materials and waste products may take place between the interior of the nerve fibre and the surrounding blood and lymph. The parts of the nerve fibre between the nodes are called internodal segments and are fairly regular in length. In each internodal segment, beneath the neurilemma, is a fairly large nucleus surrounded by a mass of granular protoplasm.

The **axon,** or **axis-cylinder,** is a direct projection from the nerve cell and the essential part of the nerve fibre. In the living state it is transparent and invisible; when treated with reagents it appears as a flattened, granular band, semisolid and elastic. It appears to be penetrated by longitudinally arranged fibrils which are thought to be continuous with the neurofibrils of the interior of the neurocyte.

Non-medullated Fibres.

These may or may not possess a neurilemma. They are grayish in appearance owing to the absence of the myelin sheath. They are found in the central nerve system and are especially abundant in the sympathetic system, where they are distributed to the non-striated muscle tissue and to the secretor epithelium, whereas medullated peripheral fibres pass chiefly to striated muscle and to the skin and other sense organs. It is customary to consider the non-medullated fibres as largely involuntary; that is, not under direct control of the will, whereas medullated fibres are largely voluntary.

Sympathetic Ganglia.

The essential parts of a sympathetic ganglion are (a) a connective tissue stroma; (b) nerve cells contained in the meshes of the network; (c) nerve fibres entering and leaving the ganglion; and (d) blood-vessels and lymph spaces. Most of the fibres are non-medullated, although those which enter the ganglion from the cerebrospinal system are usually medullated. The cells of the ganglion have freely branching dendrites so that communication within the ganglion is abundantly provided for. Those cerebro-

spinal fibres which enter ganglia are called **preganglionic** fibres, while those which leave the ganglia for peripheral distribution are called **postganglionic.** The latter, with the exception of those which go to the involuntary but striated muscle of the heart, are distributed to non-striated muscle and secretor epithelium.

Peripheral Nerve Organs.

All parts of the nerve system outside the brain and medulla spinalis are designated as peripheral nerve organs and the entire aggregation is spoken of as the peripheral nerve system in contradistinction to the central nerve system, consisting of brain and spinal medulla. The peripheral organs are the cranial and spinal nerves and the sympathetic nerves and ganglia. Each nerve is made up of a considerable number of nerve fibres, either medullated or non-medullated, bound together by connective tissue and containing blood vessels and lymphatics. Such an aggregation is called either a nerve or a nerve trunk. The nerve trunks, together, serve to connect the central nerve system with the general periphery; i. e., with all the other organs and tissues of the body and with the outside world. They are the channels through which the cord and brain receive all impressions and through which all nerve impulses from the central system are emitted.

Structure of a Nerve Trunk.

Surrounding each nerve is a thick layer of lamellated connective tissue called the **epineurium.** Transverse section of a nerve shows it to be composed of a number of bundles of fibres, each bundle invested by a separate sheath of connective tissue, the **perineurium.** Within the fasciculus the fibres are supported by a fine stroma, the **endoneurium.**

Plexuses.

A nerve trunk, being composed of a multitude of individual fibres, usually branches after traveling for a distance, and the branches from one nerve trunk may interlace with those of other trunks to form **plexuses.** The plexuses are merely rearrangements of nerve fibres which leave one trunk to enter others in order to provide wider peripheral distribution for the group of fibres arising from a given part of the central system or from a given ganglion. It must be understood that each axon pursues an independent course

to its termination even when passing through a plexus. There is no anastamosis of nerve fibres such as, in the blood-vascular system, permits a free passage of blood from one channel to another. A nerve impulse, once entered into an axon, traverses the axon to its termination, or terminations in the case of those axons which give off collaterals.

As nerve trunks pass away from their origin they tend to branch and rebranch; each branch carries its own investing sheath. The ultimate single nerve fibres are covered by a single layer of endothelial cells to the point where they penetrate or make contact with the peripheral organ to which they are distributed. This delicate, transparent membrane is the **sheath of Henle**; it is separated from the nerve fibre by a perineural lymph space to facilitate the interchange of nutrition and waste products. At their very end the individual nerve fibres may divide, each giving rise to several terminal branches, each of which possesses part of the substance and all the capabilities of the parent axon. This device permits of a wider distribution of the nerve stimulus than would otherwise be the case, one neuron sufficing to innervate several tissue cells.

Economy of Nerve Distribution.

On the efferent side of the nerve system, a single cerebrospinal neuron communicates its stimulus, by means of a spreading end-tuft, to the dendrites of several ventral horn cells in the medulla spinalis. By means of collaterals it may even communicate with groups of spinal cells at several different levels. Each of these ventral horn cells in turn gives off a single peripherally directed axon which, when it nears its ultimate destination in a voluntary muscle, may split into several terminal branches and innervate several muscle cells (*fibres*). By this arrangement it is made possible for a comparatively limited area of the brain surface to control the entire voluntary muscular system of the body, and for the slender medulla spinalis to convey to and from the brain all the multitude of stimuli which must be in constant passage. The theory that there exists in the cerebrum a separate nerve cell to control the action of every somatic tissue cell and another to receive impressions from each peripheral cell will not endure the most cursory investigation. No single fact has ever been brought forward to support it and every fact adduced by examination of nerves denies it.

Blood Supply.

The integrity and activity of nerve tissue, like that of all other living tissues, depends upon a constant process of metabolism in the course of which oxygen and nutritive materials are used up and waste products formed. In the human body this process requires the presence of blood, and although the functional activity of nerves is less directly dependent upon their blood supply than is the case in other varieties of tissue, nevertheless nerves require constant nutrition. Blood-vessels ramify the supporting framework of the nerve trunk. The arterioles subdivide into capillaries, through the walls of which and through the neurilemma, gases and materials may be interchanged with the interior of the nerve fibres.

Chemistry and Metabolism of Nerves.

Chemical analysis of nerve tissue shows it to contain water, two globulins and a nucleoprotein, neurokeratin and nuclein, two phosphorized bodies (*protagon and lecithin*), several cerebrosides (*nitrogen-holding bodies of a glucoside character*), inorganic salts, and a series of nitrogen-holding bodies such as creatin, xanthin, urea, leucin, etc. Very little is known as to the metabolic changes which actually take place but that such changes do take place is evidenced by the fact that when deprived of their blood supply nerves undergo deterioration and degenerative changes, especially in the brain. However, it has been conclusively demonstrated that the transmission of stimuli through a nerve is not immediately or directly dependent upon the blood supply. Nerves which have been stimulated for a long period and required to do excessive work show little or no change in chemical composition, whereas any other tissue under similar overstimulation would show a marked chemical change.

Withdrawal of blood from the brain is followed by immediate changes in its activity and nutrition, but experiments on peripheral nerves yield little in the way of such results.

Efferent and Afferent Nerves.

Nerves being bundles of individual axons, with their coverings, each nerve can be traced to a group of nerve cells from which the axons originate. It has been found that the direction of conduction of nerve stimuli through a nerve trunk is always away from the cells of origin along the axons. In the case of the long

dendrites which are the peripherally directed processes of bipolar cells in the spinal ganglia, this rule does not seem to hold good because these dendrites are similar in most respects to axons and are often called axons.

As to direction of conduction, three types of cerebrospinal nerves are to be found connecting the central organs with the periphery. These are: (1) Efferent nerves; (2) Afferent nerves; and (3) Mixed nerves.

The **efferent nerves** which emerge from the brain and medulla spinalis may be traced into their substance each to a group of cells called a **nucleus of origin** from which the axons spring. They conduct nerve impulses outward from the central organs and are called **motor** nerves because these impulses, when they reach peripheral organs, excite them to action.

Another group of nerves has origin in the ganglia situated upon the trunks of the cranial and spinal nerves and the axons of these ganglion cells enter the cord and brain and pass in various direction to terminate in relation to cell clusters which constitute their **nuclei of termination.** These are the afferent, or centripetal nerves. They serve to convey from their ganglia to the central organs the impressions which have been gathered at the periphery by their long dendrites and transmitted to the ganglia.

All nerves attached to the medulla spinalis are mixed nerves; each is made up of an efferent and an afferent root, the two roots attaching separately to the medulla and uniting just within the intervertebral foramen. The ventral root, attached by several strands along the ventrolateral aspect of the medulla, is the efferent or motor root; the dorsal root, attached to the dorsolateral aspect, is afferent or sensory.

Certain cranial nerves are similarly mixed, while others are purely motor or purely sensory. The mixed cranial nerves are morphologically analagous with the spinal nerves; the efferent cranial nerves with the ventral roots of the spinal nerves; and the afferent cranial nerves, with the dorsal roots. This analagy is somewhat remote in the case of the olfactory, optic, and acoustic nerves.

Peripheral Endings of Nerves.

As the **efferent nerve** nears its termination it loses both myelin sheath and neurilemma. The axon divides into a number of branches which become intimately associated with tissue cells; these terminations are called end-organs, end-tufts, or terminal organs, and vary widely in different situations.

In the **skeletal muscle** both the neurilemma and myelin sheath disappear at the point where the axon comes in contact with the muscle fibre. The axon penetrates the sarcolemma and then breaks up into a number of small branches which enter a specialized mass of protoplasm and nuclei known as a "motor end-plate." In the mammalia each muscle fibre possesses one end-plate. These end-plates are a transition substance between nerve and muscle and seem to be essential media for the change from nerve energy to muscle energy. They differ from both nerve and muscle tissue in their response to the action of certain drugs, notably curare, which fact has been made very useful in physiologic experimentation.

Fig. 89. Motor End-Plate in Skeletal Muscle. A, Base of Plate; B, Nerve End Plate; C, Nerve.

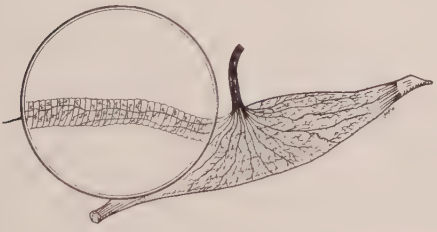

Fig. 90. Nerve Terminal in Visceral Muscle Fibre.

In **visceral muscle** the terminal nerve fibres are non-medullated, being derived from the sympathetic. At their ends the axons divide and subdivide into plexiform networks which surround the muscle fibre bundles. From these plexuses very minute fibres are given off which terminate on the surfaces of the individual muscle cells in small granular masses.

In **glands** the non-medullated peripheral nerve fibres usually penetrate the body of the gland to reach the acini, on the walls of which they branch and ramify to form a plexus. From this plexus small fibres penetrate the wall of the acinus and terminate each in the interior of a gland cell.

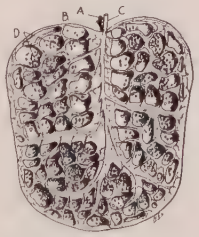

Fig. 91. Drawing of Nerve Termination in Gland Tissue.

The **afferent nerves** likewise have various modes of termination. In the skeletal muscle and in tendons the peripheral ends of afferent neurons become related to special structures called **neuromuscular** spindles. These are

small, spindle-shaped organs composed of a fibrous capsule containing from five to twenty muscle fibres. The nerve fibre penetrates the several layers of the capsule and loses its neurilemma and myelin sheath. The axon then divides into slender filaments which wind spirally around the muscle fibre and end in small oval-shaped, or button-like disks. Contraction of the muscle or tension upon the tendon compresses these disks and excites an afferent stimulus which travels to the medulla spinalis and there becomes the basis for reflex action or is transmitted to the cerebrum where it is interpreted as the muscular and tendinous sense.

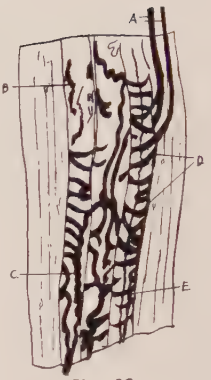

Fig. 92. Drawing of Neuromuscuar Spindle. A, Nerve Fibre; B, Axis Cylinder; C, Spiral Fibre; D, Ring-Like Axis Cylinder; E, Irregular Fibres.

The afferent nerves which terminate in the skin and mucous membranes have varied endings. Some of these are:

1. Free endings in the epithelium.

2. Tactile cells of Merkle.

3. Tactile corpuscles in the papillae of the true skin.

4. Pacinian corpuscles, attached to the nerves of the hands and feet, to the intercostal nerves, and to some other nerves.

5. End-bulbs of Krouse in the conjunctiva, penis, clitoris, etc.

The other special sense-organs are served by highly specialized and extremely complex end-organs, which intervene at the ends of the special sense nerves and gather for them the special type of stimuli to which they respond. These, including the olfactory cells of the nose, the retina of the eye, the organ of Corti of the ear, and the taste-buds of the mouth, will be considered more in detail in a later discussion of the special senses.

Nutrition of Nerves.

Every neuron possesses two functions; it is a carrier of nerve energy which may excite some other tissue to the performance of its characteristic function, or may be transmitted to another neuron at the interlacement of the end-tuft of the one neuron with the dendrites of the other. And in addition each neuron exercises a trophic or nutritive function. Whether this ability to govern the nutritive activity of the peripheral tissue to which the neuron is

distributed is a special function, apart from the conveyance of successive impulses to activity, is not definitely known. It is believed that the two functions are in a sense one; that is, that when a tissue cell, such as a muscle cell for example, is receiving from its connected efferent neurons a rhythmic discharge of nerve energy, and is thereby excited to a rhythmic and normal activity, the metabolism of that cell proceeds as a natural consequence of such activity. This theory holds that there are no special trophic stimuli passing through a neuron, and is probably the correct view. An increase in the intensity or rate of delivery of nerve stimuli would naturally excite a correspondingly increased muscle activity and this in turn would be accompanied by a more active metabolism; conversely, a diminution of the rate or intensity of the nerve stimuli would lead to a reduction in the activity of the muscle and a consequent slowing down of its metabolism.

Each neurocyte exerts a trophic influence over its processes. Just as it has been observed that a muscle deprived of nerve stimuli will atrophy, so it has been noted that a nerve process, either axon or dendrite, if cut off from its cell body, will undergo a process of degeneration. This is easy to comprehend when we recall that the processes are outgrowths from the cell body, which appears to be and to remain the center of organization of neuron life. The efferent neurons of the peripheral system, the motor fibres of the cranial and spinal nerves, are elongated processes of the pear-shaped neuroblasts which in early embryonic life occupy a position in the ventral and basal portion of the wall of the neural tube. As the embryo develops, these processes grow out and emerge from the ventrolateral surface of the medulla spinalis and join with the dorsal root fibres in the formation of spinal nerves; some of the cranial nerves are similarly formed. The fibres remain continuous at all times with the substance of the neurocyte and depend upon this continuity for their ability to take up and utilize nutritive material brought by blood-vessels to the fibre along its course.

The peripheral afferent neurons, outgrowths of the bipolar cells of the spinal and cranial nerve ganglia, are similarly dependent upon connection with their cells of origin for their ability to take up and utilize nutrition. Those neurons contained within the central axis are likewise kept in proper trophic condition by their neurocytes; and the peripheral sympathetic ganglion cells control the nutrition of their fibres.

This gives to every neuron two functions, presuming that the trophic influence of the neurons upon other tissues is the outgrowth of the same stimulation which governs general activity: each neuron is a carrier of nerve stimuli and each neuron presides over its own nutrition.

Wallerian Degeneration.

Waller was first to describe correctly the effects of section of a nerve upon the structure of the neuron. The term "Wallerian degeneration" is therefore applied to the disintegrative process which follows such section.

If a nerve be cut, the portion which remains connected with the cells of origin retains its former structure and integrity except for a few millimeters at the cut end. The portion severed from its cells of origin begins a simultaneous structural change throughout its extent. The axon and myelin sheath disintegrate into nuclei, drops of myelin, and fat, which in time are absorbed leaving only the neurilemma intact. The excitability and conductivity of the nerve, of course, diminish progressively while this change is taking place and are lost entirely when degeneration is complete.

If, for example, the ventral root of a spinal nerve is severed between its union with the dorsal root and its attachment to the spinal medulla, degeneration takes place throughout the extent of the severed fibres, external to the point of section, while the part which remains connected with the medulla remains normal save for a few millimeters of the cut end. This demonstrates that the ventral root fibres have origin in the cells of the spinal medulla and are controlled by these cells.

If the dorsal roots be severed medial to the dorsal root ganglia, their fibres degenerate upward, that is, along their course as they enter the medulla spinalis and traverse it for varying distances. The degeneration will proceed to the point where the neuron terminates by contact with the dendrites of another neuron. The peripheral portion of the cut nerves, being still in communication with the ganglion cells, remains intact.

Within the central axis, different tracts and groups of neurons have been differentiated from one another by the degenerations which follow limited section, one tract being observed to degenerate downward (*descending degeneration*) while another may degenerate upward (*ascending degeneration*). By observing this fact it is

possible to determine whether the cells of origin of a group of axons are above or below the level of the cut.

In no instance does degeneration travel from one neuron to another. This is considered conclusive evidence of the independence of the individual neuron, and of the soundness of belief that each neuron is in control of its own trophic processes.

When the nerve cells themselves undergo degeneration from any cause, their processes also undergo disintegration and loss of function. Further, deteriorative processes take place in the peripheral organs innervated by these processes, which cannot be attributed to their inactivity; inactivity leads to atrophy, but not to changes in the very structure. Anterior poliomyelitis, atrophic degeneration of the ventral horn cells of the medulla spinalis, furnishes a good example of the effects of nerve cell degeneration upon the fibres and upon the innervated muscles.

Regeneration of Nerves.

It has been demonstrated that degenerated nerves may be rebuilt. An essential condition for their rebuilding is reunion of the severed parts, reconnection with the cells of origin. When a nerve is cut in a living subject it frequently happens that the severed ends remain in such juxtaposition that it is possible for them to grow together in a variable time. In the meantime, and before such reunion has been effected, the part dissevered from its cells of origin will have undergone a varying degree of degeneration. After the reunion a regenerative process takes place.

There is first a multiplication of the nuclei lying beneath the neurilemma and a gathering around these nuclei of a granular protoplasm which eventually fills the interior of the neurilemma completely. The fibre in this stage is called a band fibre. The axon now grows from its cut end into the neurilemma, proceeding until it has finally grown to the end of the original sheath and re-established communication with its end-organs. During this growth the granular protoplasm becomes transformed into myelin.

Obviously, when function has been lost by degeneration it cannot be regained until the regeneration is complete throughout the length of the fibre. It thus happens that after a nerve has been cut the function of the part it innervates will be lost for a long period and then almost abruptly restored.

Whether neurons whose cell bodies have undergone atrophy, as in poliomyelitis, can be regenerated has been doubted. There seems, however, to be clinical evidence that this sometimes occurs. Cases of this disease showing every clinical evidence of atrophy of a group of ventral horn cells have been restored to complete functional activity.

Identity of Nerve Impulses.

The energy which passes through nerves and is by them distributed to the various organs of the body does not differ in character in different nerves, as has sometimes been supposed. That nerve energy which reaches a skeletal muscle causes that muscle to contract because it is the nature of the muscle to contract; other agencies beside the physiologic (*nerve*) stimulus can cause such contraction. The same sort of nerve energy if expended in the cells of a secreting gland will cause secretion; in different glands, varying in the structure of their cells, different secretions will be produced. Certain experiments with animals have led physiologists to believe that if it were possible to reverse the course of a nerve fibre and establish a living union the fibre would again transmit stimuli, in the direction from its cell body to its peripheral ending, as if it had not been reversed. It is also believed that the conductivity of afferent and efferent nerves is not essentially different, but that each transmits the stimuli which are provided for it.

The classification of nerves, therefore, under different functional groupings, is in reality a classification of the innervated organs, based on the situation of the different nerves, or, in the case of afferent nerves, a classification of their special end-organs, each of which is so constructed as to gather only certain special kinds of stimuli.

Efferent nerves, according to their connections, are classified as:

1. **Skeletal muscle**, or **motor** nerves, which convey energy or nerve impulses from the brain and medulla spinalis to skeletal muscles and excite them to activity.

2. **Secretor nerves**, which are distributed to glands and excite them to the act of secretion peculiar to the gland. These originate in the sympathetic system.

3. **Vaso-motor nerves**, which also arise in the sympathetic and are distributed to the non-striated muscle tissue in the walls of

the blood-vessels and control their contraction. Those nerves which increase the contraction of muscle in the blood-vessels are known as **vaso-constrictor nerves,** while those which diminish the contraction are called **vaso-dilators** or **vaso-inhibitors.** The nerves which pass to the heart are known as cardio-accelerator and cardio-inhibitor nerves according as they augment or diminish the activity of the heart muscle.

4. **Visceral nerves** are distributed to the muscular tissue of the viscera and furnish them with stimuli which induce either an increase or a diminution of muscular action. They are either viscero-augmentor or viscero-inhibitor.

5. **Pilo-motor nerves,** which are distributed to the muscle tissue which causes erection of the hair.

Of these five groups only those nerves distributed to skeletal muscle pass directly from the central organs to the peripheral tissue. The nerves to the glands, blood-vessels, viscera, and hair arise in sympathetic ganglia outside the central system and are called post-ganglionic fibres; in the ganglia they receive impulses from fibres entering the ganglia from the central nerve system and known as pre-ganglionic.

The afferent nerves may also be classified according to their distribution or according to the type of sensation to which they give rise as:

Tegumentary nerves, which are those distributed to the skin, mucous membranes, and sense organs and which transmit impressions from the periphery to the central organs, and

Muscle nerves, distributed to muscles and tendons and which serve to transmit from muscles and tendons to the brain and cord those impressions which give rise to the so-called "muscle sense" by which we become aware of the direction and duration of movement, the amount of resistence offered, and the body posture. In the cord these impressions from muscles and tendons also excite reflex actions.

The tegumentary nerves are divided into two groups, **sensorifacient** nerves and **reflex** nerves, further subdivided into:

A. **Sensorifacient nerves.**

1. Nerves of Special Sense; e. g., olfactory, optic, acoustic, gustatory, thermal, pain, pressure. These, when stimulated, give rise to sensations corresponding to the names of the nerves.

2. Nerves of General Sense; e. g., the visceral afferent nerves, which give rise normally to vague and almost imperceptible sensations such as the general feeling of well-being, of discomfort, of hunger, thirst, fatigue, sex, want of air, etc.

B. **Reflex nerves,** which transmit impressions to the medulla spinalis and medulla oblongata, where they excite the cells to different modes of nerve activity. They are:

1. Reflex excitator nerves, which transmit impressions which excite nerve centers to increased activity and therefore augment the activity of peripheral organs such as glands, blood-vessels, viscera, and skeletal muscles, and

2. Reflex inhibitor nerves, which transmit impressions which act upon nerve centers so as to diminish or inhibit their activity and therefore decrease the activity of peripheral organs.

It is believed possible that the same nerve fibre may carry impressions which both excite sensation and augment or inhibit reflex action; this is made possible by the collaterals which are given off in the central nerve system by many of the ascending fibres. A long fibre, on its way to the brain and constituting a link in the sensory pathway, may at the same time influence reflex activities on its way through the medulla spinalis.

PHYSIOLOGIC PROPERTIES OF NERVES

Irritability.

All living tissues are irritable; that is, they possess the capability of responding, in some way, to stimuli. The irritability of each tissue is expressed in accordance with the nature and structure of the tissue. Thus, the irritability of muscle tissue is evidenced by its ability to contract when stimulated; that of gland tissue by the performance of the act of secretion under stimulation. The special property of nerve tissue is **conductivity** and is possessed to some degree by all living nerve tissue. The property of conductivity is that by virtue of which nerves are able to conduct nerve impulses from the center to the periphery or nerve impressions from the periphery to the center in response to stimuli. So long as a nerve remains excitable or irritable it possesses conductivity.

It is necessary to the property of conductivity that a nerve retain its physical and chemical integrity; it must undergo no change in structure or composition. The conductivity of an **efferent** nerve is demonstrated when a muscle contracts or a gland secretes in response to stimulation of the nerve distributed to that muscle or gland. Conductivity of an **afferent** nerve is demonstrated by the fact that when stimulated it evokes either a reflex action through its centrally related nerves or a sensation in consciousness.

For a varying time after separation from nerve centers or even after death of the individual, nerve irritability continues, but as soon as chemical changes of a disintegrative nature have had time to take place in the nerve tissue, this excitability diminishes and disappears. In warm-blooded animals, in which chemical alteration is characteristically rapid, the loss of irritability is very speedy; in cold-blooded animals, accustomed to slow metabolism, the nerves may be capable of response to stimuli for a considerable time after the death of the animal. Recent experiments in the resuscitation of persons supposedly dead give rise to the question as to precisely when the event of somatic death occurs; whether at the moment when respiration and cardiac activity cease, or at some later and ill-defined moment when nerve conductivity has ebbed to the point where no stimulus will arouse it. It is too early to reach any definite conclusions from the half-dozen instances of such resuscitation on record.

Independence of Tissue Irritability.

The irritability of nerves is independent of that of muscles or glands, as shown by the fact that it persists in each for a variable time after their histologic connections have been completely interrupted. Curare, for example, introduced into the circulation, acts upon the end-organs of the nerves where they come in contact with the muscles, without impairing the irritability of either muscle or nerve tissue. Atropin similarly acts upon the nerve terminals in glands without suspending the irritability of either gland or nerve tissue. It appears that normal, healthy nerve tissue is able, of its own nature, to conduct such stimuli as may be imparted to it and, in its cells, to generate nerve impulses when excited, regardless of whether or not these stimuli are able to reach a destination and influence other tissues.

The question arises as to what becomes of the constantly generated impulses in an afferent nerve which has been cut somewhere

in its course or has been impinged in such a way as to shut off its influence from the organ innervated. These impulses pass to the point of severance in the nerve or to the obstruction or impingement which blocks their further passage, and are there lost and totally ineffective because they lack physical force or chemical potency to produce any discernible changes in tissue at the point where they are thus wastefully expended.

Nerve Stimuli.

Nerves apparently do not possess the power of spontaneously generating and propagating nerve impulses; this action seems to require that the nerve cells be aroused to activity by the action upon them of an external stimulus. This external stimulus may be chemical, mechanical, or thermal in nature, but, in the case of the efferent nerves is usually a nerve impulse; that is a stimulus generated in another neuron and transmitted to the dendrites of the efferent neuron, and thence to the cell body, in which it excites the liberation of a new nerve impulse.

In normal physiology nerves are stimulated at their central or peripheral ends almost exclusively. It has been experimentally demonstrated that a nerve will respond if stimulated at any part of its course but in actual fact stimulation rarely reaches an axon except at its origin or termination because of the coverings, which are non-conductors. Efferent nerves, therefore, usually receive their stimuli at their centers of origin, afferent nerves at their peripheral terminations.

Nerves respond to stimuli according to their nature and habit. Stimulation of a sensory nerve arouses the characteristic sensation associated by consciousness with that nerve; if the stimulus be sufficiently strong it evokes the sensation of pain. Stimulation of the optic nerve evokes the sensation of light. Excitation of a motor nerve elicits contraction of a muscle; of a secretory nerve, secretion from a gland, etc. The specific nature of a nerve function depends not upon the precise nature of the stimulus applied, nor upon any special structure of the nerve itself, but rather upon its peculiar connections and end-organs. It follows that interference with the conductivity of a nerve will result in functional disturbance in the organ or tissue supplied by it—that the special function of that organ will be diminished, whatever it may be; also that excessive stimulation of a nerve, whether physiologic or external, will result in overactivity of the innervated part.

Nerve stimuli may be classified as (a) **general stimuli,** those which may stimulate a nerve if they reach it at any part of its course, and (b) **special stimuli,** which are capable of affecting nerves only through the intermediation of their special end-organs.

The general stimuli are:

1. Mechanic. Sharp taps, sudden pressure, cutting, etc.

2. Thermic. Sudden application of heat.

3. Chemic. Contact with certain substances which alter quickly in chemical composition, such as strong acids or alkalies, sugar, urea, etc.

4. Electric. Either constant or induced current.

Special stimuli are, for afferent nerves:

1. Light vibrations acting upon the retina of the eye.

2. Sound waves, or atmospheric undulations, acting upon the organ of Corti of the acoustic nerve.

3. Heat vibrations acting upon the cutaneous end-organs.

4. Chemical agencies acting upon the special end-organs of the olfactory and gustatory nerves.

The special stimulus for efferent nerves is a molecular disturbance in the nerve cells from which the nerves arise.

Nature of the Nerve Impulse.

Little is positively known concerning the nature of the nerve impulse, which is the most important manifestation of organic life and nearest to the source of life itself. It appears to be in the nature of a progressive molecular change, propagated from molecule to molecule, and confined to the interior of the neurocyte and axon by their peculiar structure and the fact that their coverings do not share their conductivity. Experiment has demonstrated that a nerve impulse started at any point in the course of a nerve will be propagated in both directions, but under physiologic conditions such stimuli are rarely, if ever, effectively applied except at the beginning or end of a neuron. The efferent nerve conducts impulses only from center to periphery because it is stimulated only at its center; the afferent nerve conducts impressions only from periphery to center because it is stimulated only at its periphery.

The transit of a nerve impulse through a fibre is accompanied by an alteration of electric tension, the extent of which indicates the intensity of the molecular disturbance. Judging by the changes in electrical tension it appears that the nerve impulse reaches a given point at first feebly, increases rapidly to a maximum, and then as rapidly declines, the while a similar maximum may be detected at a point adjacent and in the direction of travel of the impulse. This would make it appear that the molecular agitation called a nerve impulse is wave-like in its movement. There is no visible alteration in the appearance or position of an axon during the passage of the impulse; it is entirely molecular, not molar.

The nerve impulse is therefore a transmission of energy rather than of matter. It is intangible, and can be demonstrated only by its effect upon other organs or neurons and by the change in electrical tension which accompanies its transmission. Futile attempts have been made to define the nerve impulse itself as an electrical phenomenon and to consider nerve energy as electrical energy —futile because the rate of transmission of the nerve impulse is alone sufficient to dismiss that hypothesis. Others have endeavored to explain it as a progressive chemical transformation following the course of a nerve. This explanation also fails at once because no such alteration of chemistry can be demonstrated and because the chemical condition of the nerve is not materially altered by excessive stimulation.

There is, apparently, a special form of energy, neither physical, chemical, nor electrical, which may be termed Life Energy. Its manifestations are accompanied by electrical phenomena dependent in the long run upon the presence of proper chemical conditions, and capable of inducing both physical and chemical changes in the peripheral tissues. The nerve energy itself is separate and distinct from other forms of energy.

Rapidity of Conduction.

The rate at which an impulse travels through a nerve may be modified by various factors, within reasonable limits; thus, heat accelerates and cold retards conduction; electrical conditions and the action of drugs may modify the rate. In general, however, the rate of travel in efferent nerves has been demonstrated to be from 28 to 33 meters a second, and in afferent nerves as high as 50 meters a second. The rate of transit through the medulla spinalis and medulla oblongata is appreciably slower, that for voluntary motor impulses being about 11 meters a second, for sensory impres-

sions 12 meters, and for tactile impressions about 40. This is probably due to the antagonistic or modifying influence of other neurons; most of the neurons travelling in the spinal medulla receive communications from more than one source.

Nerve Fatigue.

In a sense nerves may be said not to become fatigued as do other tissues under excessive stimulation. Continued excitation of a nerve with the induced electric current for many hours has failed to alter either the intensity or rate of conduction. While metabolism is constantly going on in nerves as in other living cells, it appears that this metabolism is at least partly dissociated from the functional activity of the nerve. The rate of chemical activity, and consequently the temperature of the nerve remains unaltered by changes in the amount of stimulation applied.

Identity of Nerve Impulses.

Although nerve impulses evoke widely varying responses according as they are carried through afferent or efferent nerves and according to the peripheral and central organs with which they are connected, there is no evidence that there exists any essential difference in the nature of the impulses transmitted through different nerves. A motor nerve excites muscular contractions because it is the nature of a muscle to contract when excited. A secretory nerve excites the elaboration and discharge of a secretion because it is the nature of gland cells to secrete when stimulated, and the precise chemical composition of the secretion is likewise dependent upon the chemistry of the gland cells. The optic nerve carries impressions which are translated in the cerebrum into sensations of light and vision because the special end-organs which gather its stimuli select only those ethereal waves which come within a certain range of vibration.

Experiment shows that any stimulus might be carried in either or both directions by any neuron, and that afferent and efferent nerves would be interchangeable if it were possible to establish living unions after transplantation.

Electric Phenomena of Nerves.

It has been demonstrated by extensive laboratory experimentation that a change in electrical tension accompanies the passage of the nerve impulse and some of the conclusions stated above as to the velocity of the impulse and its wave-like character have been confirmed through such methods of investigation. Limitations of

space forbid complete discussion of the laboratory technic of these investigations and the details of their results; they are not deemed of sufficient practical importance to be included here. One phenomenon deserves special mention; this is:

The Reaction of Degeneration.

It has been discovered that departure to any marked degree from the normal physiological conditions surrounding a nerve or from the normal structural integrity of the nerve, causes it to react differently to electric currents than the healthy nerve. When nerves are markedly degenerated this change in response is very distinct and is therefore evidential of such degeneration in nerves.

The degenerated nerve exhibits a diminished or abolished excitability to the induced current and an increased excitability to the constant current. This alteration in behavior is usually observed at its best in the muscles connected with the degenerated nerve. At times the nerve reacts normally while the muscle alone shows altered response. This is termed "partial reaction of degeneration" and is observed in progressive muscular atrophy. The term "Reaction of Degeneration" is frequently abbreviated to "R. D.," in which form it is frequently used in diagnosis of nerve disorders.

The Primitive Nerve System.

In the freshwater **hydra** may be observed the simplest form of nervous system known. The body of the hydra is made up of an outer epithelial layer and an inner epithelial layer between which lies a layer of contractile substance akin to muscle. The fibres of this contractile layer are connected with the epithelial surface by means of an intermediate tissue so that excitations of the surface are transmitted to the contractile layer through a continuous band of intermediate matter and excite contractions.

In slightly higher forms of life such as the ascidian, we find this connecting tissue elaborated somewhat into a system. The center of this system is a group, or aggregation, of cells, which may now be called nerve cells, and from which emerge fibres which serve to connect sentient or receptive structures on the one hand with active structures on the other. The action which takes place through such a mechanism is the simplest

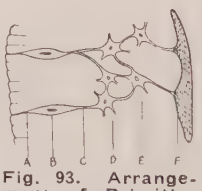

Fig. 93. Arrangement of Primitive Nerve System. A, Peripheral Process; B, Afferent (Sensory) Process; C, Central Process; D, Intercalated Cells; E, Motor Cells; F, Muscle Fibre.

form of nervous action; it is called **reflex action.** In a higher and much more complicated form this type of action takes place in the human body.

The Intercalated Neuron.

A simple nerve system consisting on the one hand of a group of neurons connected with the periphery and on the other of a group passing directly to active organs is adequate only to co-ordinate the actions of very simple organisms. As the number of cells of which the organism is composed increases, the distance between sentient surface and active organ grows greater, and the functional needs of the body become more complex, an added factor becomes necessary and is provided. This added factor is a third neuron, interposed between the receptive and emissive neurons and serving to connect them across a space. It is spoken of as an **intercalated neuron.** A single intercalated neuron may, through its branching dendrites, receive impressions from several afferent neurons and at the same time may, by way of its end-tuft, transmit stimuli to several efferent neurons. Several intercalated neurons may come into contact with the same afferent neuron and, passing in different directions, bring it into physiologic relation with different areas or segments of the efferent nerve matter. The addition of this interposed element for communication between neurons makes possible a varied distribution of the stimuli received from the periphery and a varied response to them. It permits of a much greater specialization of organs and their arrangement into systems.

In the higher vertebrata these intercalated neurons have become so numerous and assumed so great an importance as to constitute a great part of the bulk of the central nervous system. All of the tracts except those nearest the periphery both on the afferent and efferent sides may be considered as made up of intercalated neurons. The fibres drawn out from the medulla spinalis by the embryonic migration of the sympathetic ganglia, and serving to connect the sympathetic system with the cerebrospinal, belong to the intercalated group.

REFLEX ACTION

The simplest form of action which takes place in the nervous system is reflex action. The term "reflex" signifies "return of the impulse toward its point of departure by passing through that which is known as a center". In current usage, it applies to the simplest, the most uniform, and the most circumscribed of nervous acts as contrasted with those which in duration, in complexity, and

in extension through the nervous system remove from the primitive type in which they originate.

The reflex act is usually described as involuntary; that is, as not requiring the intervention of the will as a requisite of its performance. The terms reflex action and voluntary action are opposed in common usage. This distinction, however, is not absolute and the borderline between the two types of action is so indeterminate as to leave the propriety of the sharp distinction in doubt. Many acts which are at first essentially voluntary and conscious are speedily developed to the point where they become unconscious, except for the single act of will which initiates them, and are performed by means of complicated reflex mechanisms trained to the sequence of actions necessary to the accomplishment of the original purpose. Such an act, or series of acts, is walking. The newborn infant cannot walk; he must learn the art. This he does at first by intention and conscious imitation, by trial and error accumulating the experience which teaches him how the act of walking must be performed. But as this experience accumulates and habits of muscular control are formed, more and more the commanding of each individual muscular contraction is delegated to the unconscious centers in the central nervous system which we call reflex. After a time, the only thing necessary for the child's conscious mind to do is to will the act of walking, its speed, and direction. His nerve centers will do all the rest until commanded to cease or to alter their action or until some insuperable obstacle arises.

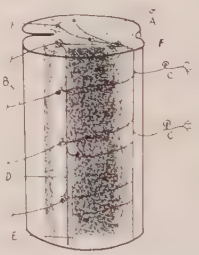

Fig. 94. Diagram of Segment of Spinal Cord to Show Mechanism of Reflex Action. A, Spinothalamic Fibre; B, Ventral Root Fibre; C, Peripheral Ganglion; D, Long Associative Neuron; E, Short Associative Neuron; F, G, Ascending Dorsal Root Fibres.

The simpler reflexes, and those concerned with the vegetative functions of the body, do not require to be learned and initiated in this way. They are born into the structure of the neurons so to speak, or in other words, the neurons possess by their nature the capability of responding to peripheral stimuli which are abundantly provided by the contact of the newborn with the outside world and by the actions of the body itself, all of which give rise to stimuli.

The Simple Reflex.

We proceed from the study of the simplest reflexes to the more complicated co-ordinated reflexes. For the simple reflex a mechan-

ism is required, called a "reflex arc", and consisting of the following essential parts:

1. A receptive surface—skin, mucous membrane, special sense-organ, etc.

2. An afferent neuron.

3. An efferent neuron, with its emissive cell and projected efferent fibre, which is distributed to

4. A responsive organ, such as muscle, gland, blood-vessel, etc.

In the simplest reflex arcs are but two neurons, afferent and efferent. Such an arc is that which supplies the skeletal muscles, from which afferent nerves pass to the brain or medulla spinalis in the dorsal roots of the cranial and spinal nerves and there come into relation with efferent neurons, from which the fibres pass with the ventral nerve roots to the muscle from which the stimulus comes.

In the case of the glands and non-striated muscle fibres such as those found in the walls of blood-vessels, the afferent neurons terminate by arborizing around the cells of a sympathetic ganglion, from which the efferent neurons emerge to return the impulse to the periphery. The ganglion in this case is known as the reflex center, just as cell groups in the medulla spinalis and brain are similarly designated. A ganglion or a nucleus in the central system may be at the same time a center for reflex action and a relay station for impulses generated in higher centers.

The majority of reflexes are complex. They involve the co-operation of various responsive organs often situated at some distance from one another. This requires that different sets of efferent neurons be brought into action by excitation of their centers in the medulla oblongata or medulla spinalis and for this purpose numerous intrinsic or intercalated neurons are brought into play.

In order that the response to the stimulus may be properly timed, so that the several responsive organs may act serially in the performance of some function such as deglutition, the mechanism is so arranged that the stimulus is propagated in turn to the various centers which must co-operate.

Nature of the Reflex Act. In order that a reflex may be evoked it is essential that a stimulus be applied to the surface which is sufficiently intense to develop in the terminals of the afferent nerve a series of nerve vibrations which, travelling centralward, will

be distributed to and received by the dendrites of an emissive cell. The reception of these stimuli seems to create in the emissive cell a molecular disturbance with a liberation of energy and, in consequence, the generation of a new impulse which travels outward over the efferent fibre and excites, in the organ to which it is distributed, the characteristic action of that organ; i. e., secretion in a gland or contraction in a muscle or blood-vessel. A perceptible time is required after the impression is received before the responsive impulse emits from the cell.

Selection and Inhibition.

While reflex action is often spoken of as "automatic" it is not to be understood that each impression reaching a reflex center invariably and unavoidably evokes a peripherally directed impulse. All reflex centers are in contact with the terminals of intercalated neurons from various sources, some from other equi-potent centers and some from higher centers. Thus the nuclei in the ventral horns of the spinal medulla, which are reflex centers for the action of the skeletal muscles, are at the same time in contact with the terminals of cerebrospinal fibres arising in the pre-central area of the cerebral cortex; these cerebrospinal neurons exert over the lower centers the power of inhibiting, to some extent, their response to peripheral stimuli. Two influences are brought to bear upon the cord centers, the one through afferent neurons tending to excite action and the other through descending cerebrospinal neurons tending to check, retard, or inhibit action. The balance between these two counter-influences determines the degree and intensity of response at any given time to a given stimulus. If the stimulus through afferent nerves be sufficiently intense it may overcome entirely the inhibitory influence of the brain and cause action which is not merely involuntary but actually contrary to the will. Some pain stimuli have this effect. On the other hand, by a deliberate exercise of will it is frequently possible to prevent actions which would ordinarily take place reflexly without the intervention of the mind. The act of defecation is an example. In infants it is purely reflex; in adults it may be reflex if the mental control is relaxed for any reason, but is usually initiated by a deliberate withdrawal of cerebral inhibition which would otherwise prevent it.

Storage of Impulses.

The nerve system seems to possess the capacity for storing for a variable time the impressions it receives and thereafter re-

leasing them. An impression which does not at once evoke a responsive action may, together with others similarly stored up, become a basis for future action. This is the foundation of memory, association of ideas, etc. It is this basic capability of storage and retarded utilization of impressions which makes possible all education, from the simple education of nerve centers to perform reflex acts up to the highest mental manifestations.

Location of Reflex Centers.

Most of the reflex centers are located in the medulla spinalis and medulla oblongata, but some of the higher and more important ones are found higher in the brain; the cerebellum, for example, acts as a great reflex center for the co-ordination of those synergic muscular movements necessary to locomotion, prehension, and the maintenance of equilibrium. There are in the cerebrum numerous very important centers for the government of systematic functions.

Inhibition, Paralysis, Fatigue.

Study of the simple reflex act would seem to lead to the conclusion that the transference of a stimulus from an afferent nerve to an efferent must always and inevitably lead to activity of the organ served by the latter; this is not the case as shown by certain experiments. There are instances in which activity of the motor, or efferent, neuron is followed by a state of rest, inactivity, or relaxation in the innervated organ. The best example of this is found in the action of the heart. The heart is supplied with two sets of nerves, the one derived from the sympathetic by way of the cervical cardiac nerves and the other arriving through the vagus. Excitation of the former accelerates the action of the heart, while excitation of the latter retards it. The vagal cardiac fibres are termed **cardio-inhibitor** and the name "inhibition" has been given to their effect.

This term must be carefully distinguished from "paralysis" and from "fatigue." Paralysis is a condition in which the nerve has lost its power of conveying impulses, while inhibition is the normal result of the conveyance of stimuli by a nerve. Fatigue is a condition in which the nerve, through overwork or improper metabolism, has its conductivity diminished and as a consequence the activity of the responsive organ is reduced. Certain drugs, like curare, have been incorrectly described as inhibiting the action of

nerve endings when, in fact, the phenomenon following their use is paralysis.

The usual and normal influence of cerebrospinal neurons upon the ventral gray matter of the spinal medulla is to inhibit their reflex excitability. When this influence is diminished or lost, as in lesions of the lateral funiculus of the cord, the reflex centers below the level of the lesion respond with great intensity to ordinary peripheral stimulation.

SPECIAL PHYSIOLOGY
OF
NERVE ORGANS
PART II

The neurons of which the nervous system is composed are aggregated together into groups called nerve organs, for the reason that such a group or aggregation may, by the association of its neurons for some common purpose, accomplish the direction of some systemic function of the body or otherwise perform work which would be beyond the power of any single neuron.

The nerve organs are divided into two groups; the **central organs,** the brain and medulla spinalis, and the **peripheral organs** including the ganglia and nerve trunks outside the central organs. Each group is further subdivided within itself. Thus each ganglion of the sympathetic may be considered an organ in that its cells are associated in the performance of some function common to all of them and differing from the function of another ganglion in that the distribution of its axons is to an organ having its own special use in the body. In speaking of the difference between the functions of nerve organs it should be remembered that all alike generate and propagate nerve impulses and do nothing else, and that the functional distinction between nerve organs depends rather upon the distribution of their impulses than on any essential differences in the organs themselves. Thus a sympathetic ganglion may be spoken of as a vaso-motor center because its axons pass to the walls of blood-vessels, while an area of the cerebral cortex may be described as a center for hearing because it is in receipt of fibres which convey from the acoustic apparatus those special impressions due to atmospheric undulations and interpreted as sound.

In this section we shall first explore the nervous system and discuss the functions of its various parts; then take up in turn the principal systemic activities of the body and describe the nervous mechanism which controls each, with some explanation as to the manner in which it acts. Such explanations will be necessarily incomplete, both because knowledge of the functions of nerve organs is as yet far from complete and because the limitations of space forbid detailed discussion of all the experiments which have led scientists to diverse conclusions, and the conflicting theories which are still held with regard to certain phases of nerve activity.

General Function of Nerve System.

The function of the individual neuron is to generate within its neurocyte and to transmit through its processes, wave-like undulations of its molecular contents known as nerve impulses. The nervous system as a whole possesses two systematic functions: first, to regulate, direct, and co-ordinate the purely internal activities of the body, and, second, to establish and maintain the relationship of the body with its environment.

For the accomplishment of the first of these functions it is necessary that every organ in the body be under the direction of nerves and that these nerves have such communications with each other as will enable them at all times to harmonize the action of each organ with all the others, otherwise organic anarchy would ensue. It is not to be understood that the energy by virtue of which an organ performs its natural function is furnished to it through the nervous system; that energy is liberated in the organ itself as a result of combustion, chemical combinations taking place between oxygen, brought by the blood, nutritive materials, also supplied by the blood, and the substance of the tissue itself. The nerves **direct** this combustion as well as the distribution of the materials which enter into it; they regulate the activity of the organ as a superior officer directs the laborer without actually supplying him with the energy needed to do his work.

For the establishment and maintenance of man's relation with his environment there are necessary a complete set of afferent or sensory nerves having the peripheral terminations of their dendrites located in the skin, mucous membranes, or special sense organs and serving to pour into the central nerve system a flood of impressions constantly received through the contact of man with the world outside himself. Also there must be a complete set of efferent or motor nerves conveying to all the skeletal muscles the commands which enable them to accommodate the body to its environmental needs, to move it from place to place or from attitude to attitude, to protect it from menaces which might injure it, to provide it with food, to utilize it for the performance of work deemed essential to the body welfare.

Lastly, and most important, there must exist in man groups of highly specialized neurons whose duty it is to assemble the data brought them from the outside world and determine which shall be responded to and how, to discriminate between impressions and to judge them, and to decide upon courses of procedure. There

must be **consciousness** and **will,** linked together by the power of **intelligent reasoning.** Consciousness, reasoning, and will have been separately classified as "psychical faculties" and they undoubtedly occupy the highest position among the varied forms of nerve activity, but there is every reason to believe that they require for their performance groups of nerves, similar to other nerves, capable of generating and transmitting nerve impulses, and differing from the others largely in their multitudinous associations. The seat of these higher nerve functions is in the cortex of the cerebrum; there are gathered in small compass the greatest number of nerve cells to be found anywhere and these cells have the most numerous associations and connections with other cells; also they are so situated as to receive not merely limited information from a small section of the body but a sufficient amount of information from all the body to make possible reactions of general service.

FUNCTIONS OF THE MEDULLA SPINALIS

In order to comprehend the functions of the medulla spinalis it will be necessary to review its structure, for which see pages 14 to 29.

The gray matter of the spinal medulla is composed of nerve cells, the fibres projected by or communicating with these cells, neuroglia, and blood-vessels. It is more vascular than the white matter because the nutrition of the neuron is presided over by its cell body and cell bodies predominate in the gray, whereas the white substance is largely composed of nerve fibres, with a limited amount of supporting tissue.

Gray Substance.

Three types of cells are found in the gray matter, according to the distribution and function of the fibres to which they give origin. They are **intrinsic, afferent,** and **efferent.**

The **intrinsic cells** are those which give origin to fibres to be distributed wholly within the central axis. These fibres, after leaving the cell, may either ascend or descend and may be distributed on the same side (*associative fibres*) or on the opposite side (*commissural fibres*). After traversing the white substance for a variable distance the intrinsic fibres re-enter the gray matter where they terminate by arborizing in relation with the dendrites of other cells.

They serve to convey nerve stimuli from one set of neurons to another. Thus an impression arriving over an afferent nerve may, by means of an associative neuron, be transferred to the cell of an efferent neuron in the ventral horn at the same level. Or the impression so arriving may, by an associative neuron, be transferred up or down the cord to ventral horn cells in higher or lower segments, so as to spread the response to the stimulus. Or, by means of intrinsic neurons of a commissural nature, the stimulus may be carried across from the side of its entrance to the opposite side to evoke responsive action from motor cells.

Intrinsic cells are widely disseminated throughout both the dorsal and ventral gray matter; they are not limited to a special locality but are most numerous around the periphery of the gray column, so that their fibres may pass directly out of the gray into the white substance and traverse an area of white substance directly contiguous to the gray before re-entering the latter. This zone of associative fibres immediately surrounding the gray column almost throughout its entire extent and circumference is known as the **fasciculi proprii,** or ground bundles.

The **afferent cells** are situated chiefly in the dorsal portion of the gray matter. They are sentient or receptive in function. Their dendrites receive the terminals of afferent peripheral neurons which bring in impressions which, when relayed to the cerebrum by the afferent cells of the cord, give origin to sensations of touch, pain, temperature, posture, weight, etc. The afferent cells of the spinal medulla with their centrally directed axons which ascend the medulla are links in the sensory pathway which begins with the peripheral sensory neurons of the dorsal roots of the spinal nerves and ends in the cerebral cortex.

The **efferent cells** possess a trophic influence over the organs they innervate as well as over their own fibres. In addition to the trophic function, they are **motor;** that is, they originate and send forth impulses which, when they arrive at the terminal organ to which the nerves are distributed, evoke the characteristic activity of that organ. The efferent cells of the medulla spinalis are located in the ventral portion of the gray matter. Most of them are motor to skeletal muscles and are links in the pathway for voluntary motion which begins in the precentral area of the cerebral cortex and terminates in skeletal muscles. These may also be centers for reflex action, in that they possess the capability of responding to stimuli received through afferent neurons directly, or from afferent

neurons indirectly through the intrinsic neurons. Some of the cells of the ventral gray distribute their axons by way of the sympathetic system, in the ganglia of which they terminate in relation to the dendrites of ganglionic cells from which new axons arise to complete the pathway to the viscera, blood-vessels, glands, etc. These cells are also motor in function but serve involuntary and unconscious motion rather than voluntary motion; they are termed vaso-motor, viscero-motor, pilo-motor, and secretor cells, according to the ultimate destination of their impulses.

In general the efferent cells are arranged in longitudinal columns in the ventral horn. Those whose axons pass to the sympathetic lie near the base of the horn and near the central canal. The skeletal motor cells are in two major groups, the antero-median column and the postero-lateral. The cells are most numerous, as might be expected, in the cervical and lumbar enlargements, from which the movements of the fore-limbs and hind-limbs are controlled.

THE WHITE SUBSTANCE

The white substance of the medulla spinalis is composed of medullated nerve fibres with a limited amount of supporting tissue. The active elements are the white fibres and these are all conductors of nerve impulses derived from their respective cells of origin. Histological investigation has made possible the observance of many separate **tracts**, to each of which may be attributed a special function.

A tract or fasciculus, is a group of fibres having a common origin, a common termination, and a common function. Its fibres are morphologically homologous. Three methods have been chiefly employed in determining the outline and extent of the various tracts; observation of their embryonic development; observation of the results of limited section of the spinal medulla, cerebrum, or nerve-roots in animals; and study in the human subject of the effects of pathological conditions the precise location and nature of which are afterward ascertained by autopsy. By these methods the existence of a number of clearly defined tracts has been established and also the presence of other less sharply demarcated areas. Some tracts mingle with others so that it is virtually impossible to say where one group of fibres ends and the other begins. The functions of certain small regions in the medulla spinalis are still in doubt.

Definite functions may, however, be ascribed to most of the white substance.

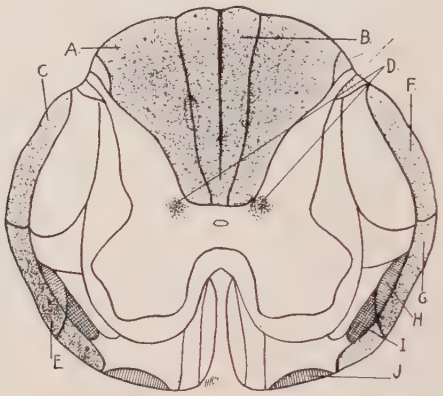

Fig. 95. Drawing of Transverse Section of Cord with Afferent Tracts Shaded.
A, Fasciculus Cuneatus; B, Fasciculus Gracilis; C, F, Spinocerebellar Fasciculus; D, Dorsal Nuclei of Gray Matter; E, G, Ventral Spinocerebellar Fasciculus; H, Lateral Spinothalamic Fasciculus; I, Spinotectal Fasciculus; J, Ventral Spinothalamic Fasciculus.

For convenience the white substances is divided into a dorsal funiculus and a ventrolateral funiculus, and the latter again into ventral and lateral portions.

Dorsal Funiculus.

This is the portion of the white substance which lies between the dorsal horn and the dorsomedian septum. It is subdivided into two tracts, or fasciculi, a more lateral **fasciculus cuneatus**, and a more medial **fasciculus gracilis.** These two fasciculi might be termed one were it not for the fact that in the cervical region they are separated by a fibrous partition and in the medulla oblongata they terminate in relation to two separate, though similar, nuclei.

The axons of which these fasciculi are composed are derived from the entering dorsal roots of the spinal nerves. Their fibres ascend, those from each successive nerve lying lateral to those from the next nerve below and crowding that layer nearer to the median line. It follows that in the upper half of the cord the fasciculis gracilis is composed of fibres derived from the lower half of the series of spinal nerves while the fasciculus cuneatus contains fibres entering from the upper half of the series.

The fasciculus gracilis terminates in the medulla oblongata by the arborization of its fibres in relation to the cells of the **nucleus**

gracilis. The fasciculus cuneatus terminates similarly in relation to the **nucleus cuneatus.** From these two nuclei new axons arise which ascend, decussate above and posterior to the pyramidal decussation, and continue upward as the medial lemniscus, or fillet, through pons, and mid-brain, to terminate in the optic thalamus. In the thalamus a third set of neurons continues the pathway to the post-central area of the cerebral cortex.

These two fasciculi carry afferent impressions derived from the skin, mucous membranes, and the sensory end-organs in the muscles and tendons which, when they reach the cortex, evoke in consciousness the sensations of touch, and of the position and motion of the parts of the body and the resistence encountered by them. Briefly, these fasciculi convey the muscular and tendinous sense and touch. They are ascending tracts. If cut, they degenerate upward, showing that the origin of their fibres is below in the cells of the spinal ganglia, and the degeneration ends at the nuclei cuneatus and gracilis.

The **fasciculus of Lissauer** is a small tract embracing the tip of the dorsal horn but usually described as part of the dorsal funiculus. It is afferent in function. Its fibres are derived from the entering dorsal roots of the spinal nerves and after entering the tract they divide into ascending and descending branches which terminate by arborizing around the cells of the dorsal horn.

Some of the dorsal root fibres which enter the fasciculus cuneatus divide into ascending and descending branches; the descending branches, which are short, curve downward in a group which in transverse section appears at the line of junction between the cuneate and gracile fasciculi; they enter the gray matter after descending but a short distance. This tract is known from its situation by the unnecessarily cumbersome name of **fasciculus interfascicularis;** it was formerly called the **comma tract of Schultze,** from its shape and after its discoverer.

The posterior funiculus contains, in addition to the fasciculi, described, numerous associative fibres. Most of these are arranged in a layer which surfaces the posterior gray matter under the name of the **fasciculus dorsalis proprius;** some, however, which are descending associative fibres, are gathered into a bundle lying adjacent to the dorsomedian septum and called the **septomarginal tract.** The septomarginal tract with its fellow of the opposite side, from which it is separated only by the septum, constitutes what is called the **oval tract of Flechsig** in the lumbar region.

Lateral Funiculus.

In contact with the entire surface of gray matter in the lateral and anterior regions of the medulla spinalis is a thick layer of white matter usually described in two parts, the **fasciculus lateralis proprius** and the **fasciculus proprius anterior** (*O. T. antero-lateral ground bundles*). These are made up of fibres which, leaving the cells of the gray matter, traverse the white matter for a distance of one, two, or several segments, and then re-enter the gray matter and terminate by arborizing in relation with the dendrites of its cells. The proper tracts are therefore associative in function and serve to convey impulses from one segment of the gray matter to another, for the purpose of establishing co-ordination.

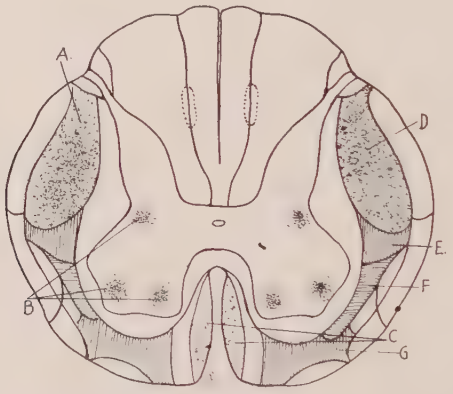

Fig. 96. Drawing of Transverse Section of Cord with Efferent Tracts Shaded.
A, Fasciculus Cerebrospinalis Lateralis; BB, Efferent Pathways in Ventral Horn; C, Fasciculus Cerebrospinalis Ventralis; E, Fasciculus Rubrospinalis; F, Fasciculus Tectospinalis; G, Fasciculus Vestibulospinalis.

The lateral funiculus contains, in addition to its intrinsic fibres, several ascending and several descending tracts. The best known ascending fasciculi are the **dorsal spinocerebellar fasciculus**, the **ventral spinocerebellar**, and the **lateral spinathalmic**; the principal descending fasciculi are the **lateral cerebrospinal** (*crossed pyramidal tract*) and the **rubrospinal fasciculus.**

The **dorsal spinocerebellar fasciculus** (*direct cerebellar tract*) is situated at the periphery of the cord in the dorsal portion of the lateral column. It derives its axons from the cells of Clark's column at the base of the dorsal horn and consequently begins, not at the extreme lower level of the cord but about the level of the first lum-

bar segment, augmenting in size as it ascends. When cut, the fibres of this tract degenerate upward, showing that it is an ascending tract. Its axons after entering the medulla oblongata pass by way of the inferior peduncle to the cerebellum.

Clark's column receives from the entering dorsal root fibres of the same side impressions of touch and of the state and action of muscles and tendons. These impressions evoke in the cells of Clark's column a new set of similar impulses which are transmitted upward through the dorsal spinocerebellar tract to the cerebellum, where they are utilized as a basis for the complicated reflexes by which that organ controls and maintains the equilibrium of the body and organizes the synergic action of its muscles. Briefly, the dorsal spinocerebellar tract conveys touch and the muscular and tendinous sense from the dorsal gray matter of the cord to the cerebellum.

The **ventral spinocerebellar fasciculus** and the **lateral spinothalamic** are in close anatomical association at the margin of the cord ventral to the dorsal spinocerebellar tract and dorsal to the line along which the ventral nerve roots emerge; so closely are they associated that it is difficult to delimit them. Each contains fibres probably derived from the dorsal and intermediate gray matter of both the same and opposite sides; those from the opposite side cross in the ventral commissure chiefly. The **spinothalamic tract,** in addition, contains some fibres directly derived from the dorsal roots of the spinal nerves of the opposite side.

The ventral spinocerebellar tract conveys to the cerebellum impressions originally derived from muscles and tendons of both sides, and utilizable as a basis for unconscious muscular co-ordination and reflex tonus. The spinothalamic tract conveys bilaterally derived impressions of pain and of temperature to the optic thalamus.

Medial to the afferent fasciculi and lateral to the fasciculus proprius are interposed at least two, and possibly more, efferent or descending fasciculi. These are the **lateral cerebrospinal** and **rubrospinal fasciculi,** the former lying near the dorsal margin of the lateral funiculus, medial to the dorsal spinocerebellar tract, and the latter adjacent and just anterior to the cerebrospinalis.

The axons of which the lateral cerebrospinal tract is composed arise in the pyramidal cells of the precentral area of the cerebral cortex, descend through the corona radiata and the anterior two-

thirds of the retrolenticular limb of the internal capsule, the middle three-fifths of the crusta of the mid-brain, and the pars basilaris pontis, and enter the upper part of the medulla oblongata as the **pyramids.** In the lower half of the medulla the major portion of this group of fibres undergoes decussation; i.e. intercrosses from one side to the other with a similarly crossing bundle from the opposite side, and the fibres which thus decussate move dorsalward into the lateral funiculus, in which they descend as the lateral cerebrospinal fasciculus.

The axons of this tract enter the ventral gray matter in successive groups as the tract descends, and for this reason the size of the tract diminishes from above downward. Its axons terminate by an arborization in relation with the dendrites of the motor cells of the ventral horn, or communicate with them by means of intercalated neurons. Their function is two-fold; to transmit to the motor cells of the ventral horn impulses derived from the cerebral cortex and which direct the voluntary contractions of skeletal muscles, and to inhibit the ventral horn cells so as to modify their response to stimuli from the periphery.

The lateral cerebrospinal fasciculus, like the ventral cerebrospinal fasciculus, forms part of what is termed the **direct motor pathway.** Contradistinguished from this is the **indirect motor pathway** which leads from cerebral cortex to cerebellum and thence to the centers in the spinal medulla. The final link in each pathway is the same as in the other, namely, the set of peripheral motor neurons arising in the ventral horns of the cord and ending in skeletal muscles. Both the direct and the indirect set of upper neurons act upon these cord centers, the one to command voluntary action and to inhibit reflex excitability, and the other to command involuntary or unconscious muscular activity.

The dividing line between the spheres of influence of these two pathways which converge upon the lower neurons is not at all clearly defined. Muscular actions which are usually unconscious may in many cases be voluntarily performed, or at least initiated. On the other hand, actions which we are accustomed to perform only as a result of an act of will may, under unusual circumstances, be performed without the apparent intervention of consciousness.

The fasciculus in the lateral column of the cord which subserves the indirect motor pathway chiefly is the **rubrospinal fasciculus.** It arises in the cells of the red nucleus of the tegmentum of the mid-brain. Its fibres decussate in the median raphe shortly after leav-

ing the cells, and then descend through pons and medulla and through the lateral funiculus of the cord just ventral to the lateral cerebrospinalis. Fibres are given off by this tract as it descends, so that it progressively diminishes; they pass into the gray matter of the same side and terminate by an arborization in relation with the ventral horn cells or communicate with them by means of intercalated neurons.

Tracts of the Ventral Funiculus.

The fasciculus proprius ventralis (*anterior*) has already been mentioned as a layer of associative fibres closely investing the ventral gray matter. In addition this column contains one well-defined descending tract, the **fasciculus cerebrospinalis anterior.** This lies adjacent to the ventromedian fissure, and is composed of axons derived from the precentral area of the cerebral cortex. These axons pass through the brain with those of the lateral cerebrospinal tract until they reach the pyramidal decussation in the medulla. There they continue uninterrupted and descend the ventral column of the cord as far as the lower thoracic region. As the tract descends it gives off successive groups of fibres which cross in the ventral commissure and come into relation, directly or indirectly, with the ventral horn cells of the opposite side.

Thus all the fibres of the direct motor pathway decussate between their origin and their termination in the cord; the major portion, those in the lateral fasciculus, cross in the medulla; the lesser portion, those in the ventral fasciculus, cross in successive groups just prior to ending in the cord. The function of the ventral cerebrospinal fasciculus, like that of the lateral, is to convey impulses to voluntary motion to the cord centers, and to inhibit the reflex excitability of these centers.

Three lesser fasciculi appear in the ventral funiculus. The **vestibulospinal fasciculus,** arising from Deiter's nucleus and descending throughout the length of the cord, carries to ventral horn cells impulses which have to do with the maintenance of equilibrium. It is part of a reflex pathway the afferent limb of which starts in the semicircular canals of the ear.

The **tectospinal fasciculus** arises in the superior colliculus, decussates, and, descending, serves the purpose of reflexes arising from visual impressions. It may be classified as a part of the indirect motor pathway, like the vestibulospinal tract.

The **ventral spinothalamic fasciculus** lies close to the line of emerging ventral nerve roots and is therefore very closely associated with the lateral spinothalamic tract. Like the latter, it carries axons from the gray matter of the same and the opposite side and conveys impressions which will ultimately be translated into sensations of pain, heat, or cold.

The Anterior Commissure.

The anterior white commissure is made up of medullated nerve fibres which cross the cord from side to side, and may be regarded as a decussation. It contains: (1) fibres from the anterior cerebrospinal fasciculus; (2) collaterals from both the anterior and lateral funiculi; (3) axons from cells in the gray matter; and (4) dendritic processes from some of the medial anterior cells.

The Posterior Commissure.

The posterior gray commissure has a large amount of gray matter and neuroglia but through it pass many nerve fibres whose function it is to establish relationship between the gray cells of the two sides. These fibres are truly commissural in function.

Relation of Spinal Nerves to Spinal Medulla.

The anatomical relation of the spinal nerves to the cord has been described. (pages 154 to 157). Physiologic experiments conclusively prove that the anterior root fibres are the axons of groups of cells situated in the anterior horn of the cord on the same side as that on which the nerve emerges, and that the posterior root fibres are the centrally directed processes of the cells of the spinal ganglia, whose peripherally directed processes make up the sensory fibres of the spinal nerve. The anterior root fibres are therefore motor or efferent in function, the posterior root fibres sensory or afferent.

Division of the anterior roots results in:

(a) Relaxation of skeletal muscles and loss of tone and of movement, followed by atrophy.

(b) Temporary dilatation and loss of tonus of the blood-vessels.

(c) Cessation in the discharge of secretion from glands.

(d) Temporary impairment of the activities of the visceral muscles from loss of central nerve control, the degree of impairment depending on the nature of the viscus involved.

Stimulation of the anterior roots produces:

(a) Tetanic contraction of skeletal muscles.

(b) Changes in the tonus and degree of contraction of the arterial muscles, either augmentation or inhibition.

(c) Discharge of secretions from glands.

(d) Variations in the contractions of the muscle walls of the viscera, either augmentation or inhibition.

From these and other experiments many conclusions have been deduced; among them, it is believed that the anterior root fibres not only convey to skeletal muscles the impulses which govern their contraction, both voluntary and involuntary, but also preside over their nutrition. It is further shown that the ventral roots contain fibres which influence the action of those organs directly presided over by the sympathetic, but that the impulses which pass from the central system to the sympathetic are not the only ones to reach the viscera, glands, and blood-vessels. It appears that the sympathetic ganglia have power to respond reflexly to stimuli arriving from the periphery and to send out impulses which will keep the vegetative organs in a state of activity independent of cerebrospinal control, but that this independence is limited and the sympathetic system incapable of inducing **perfect** action without its directing force.

The positive effects of stimulation of anterior nerve roots as shown in the vegetative organs exceeds the negative effect which follows section; that is, it appears that the cerebrospinal neurons exert a definite influence which can modify or control the action of the sympathetic but that when this influence is withdrawn the ganglia are capable of continued activity within their respective areas of influence; this activity, however, in the absence of cerebrospinal direction, lacks co-ordination, and inharmony between internal organs develops.

Division of the posterior roots is followed by:

1. Loss of sensations in all parts to which they are distributed.

2. Loss of the power of exciting or inhibiting the reflex activity of nerve centers and consequent loss of influence over the actions of peripheral organs.

Peripheral **stimulation** of the posterior roots produces:

1. Sensations of touch, pressure, temperature, and pain.

2. Sensation of the duration and direction of muscle movement, of the resistance offered to such movement, and of the position of the body and its individual parts (*muscle sensations.*)

3. Excitation of spinal centers in consequence of which there is an increased reflex activity of skeletal muscles, blood-vessels, glands, and visceral walls.

4. Inhibition of spinal centers in consequence of which there is diminished reflex activity of skeletal muscles, blood-vessels, glands, and viscera.

The posterior roots are therefore afferent in function. They convey impressions to (a) the spinal cord, in which they excite its nerve centers to reflex activity, (b) the cerebrum, where they evoke in cerebral nerve centers various sensations and (c) the cerebellum.

Superior and Inferior Planes.

It becomes necessary at this point to introduce a concept of the structure of the nerve system which is difficult both of explanation and comprehension but which, if clearly visualized, will greatly aid the student in understanding the functional relationship between the different groups of neurons. It requires imagination.

In primitive nerve systems which serve simple bodies arranged in a series of somewhat similar segments, the nerve centers are usually placed in a linear series, ranged in a row along the central axis of the animal body. From each center fibres, both efferent and afferent, connect with the peripheral substance in the same zone or segment which contains the center. For co-ordination of centers associative fibres pass between the centers.

As the nerve system becomes more complex and its functional associations more varied, the number of intercalated neurons is greatly increased. The cells of some of these neurons withdraw in time from intimate association with the central axis and aggregate themselves in separate masses. These cell masses, assuming more and more the direction of the primary nerve centers and being subjected to an increasing flood of impressions from a periphery which is coming into more and more varied relations with the outside world, develop a transcendent importance. They are the rudiments of the cerebral cortex, remaining connected with every part of the central axis, from which they derive information and to which they send forth commands, both of an exciting and an inhibiting character.

At the same time the simple axial arrangement of the nerve cells is further modified by the fact that, during the growth of the

body, many of the neurons retain their connection with migrating peripheral organs not by the mere elongation of their processes as is the case with the neurons controlling skeletal muscle, but by a migration of the nerve cells away from the central axis and into close proximity with the innervated organs. This is especially true of these neurons whose duty it is to innervate the organs concerned directly with the life of the individual, the nutritive organs. Thus the sympathetic system is formed by a series of neurons drawn out from the central axis but retaining communication with it. The fibres which follow the migrating ganglia of the sympathetic may be considered as belonging to the system of intercalated neurons.

Thus in the mechanism which controls the vegetative organs, the neuron passing from ganglion to periphery is homologous with the neuron passing from the ventral horn of the cord to the skeletal muscle. The neuron which passes from the medulla spinalis to the sympathetic ganglion is similar to that which descends the medulla spinalis from the cerebrum to reach and influence the ventral horn cells.

All nerve activities may be spoken of as operative in two planes, a **superior** and an **inferior.** But the upper margin of the inferior plane is not, as might at first be supposed, entirely contained within the medulla spinalis and its continuations upward in the form of the central gray matter of the brain. On the contrary, the margin of the inferior plane is irregular; in the case of the pathways to skeletal muscles it lies, in fact, in the central axis; in the pathways to the blood-vessels, glands, and visceral muscles it lies either in the gangliated cord or in the collateral ganglia which lie, sometimes, in the very walls of the innervated organs. Thus some of the lower neurons are very short while some are very much elongated.

The arrangement of the superior plane is by no means as simple as the first statement of the concept would suggest. Its cell groups, instead of remaining in a core or axis parallel with the margin of the inferior plane, have been aggregated headward, drawing their communicating fibres with them so that the latter, instead of stretching lateralward from the gray matter of the cord, closely envelope that gray matter in a thick sheath of white fibres. Furthermore, instead of a single upper neuron connecting the inferior with the superior plane, we find more than one in most cases linked end to end, an arrangement which allows for much greater

diversity in the distribution of impulses and impressions within the central nerve system.

Segmentation of Medulla Spinalis.

For the elucidation of many problems connected with the physiologic action of the medulla spinalis it will be well to consider its gray matter as consisting physiologically of a series of segments, superimposed one upon the other, and each segment comprising that portion of the gray matter to which is attached one pair of spinal nerves. This segmentation is not exact and clearly defined in the human subject, but is sufficiently marked to be a great aid to study. The nerves of each segment come into histologic and physiologic relation with definite areas of the body; that is, each pair of nerves, either directly or through its connections with the sympathetic, has a specific sphere of influence in the body. If the precise area of distribution of any spinal nerve be known, the function of its cord segment can be exactly stated.

By virtue of this segmentation it becomes possible for each segment to act independently, or in co-operation with other segments, near or remote, to which it is connected by intrinsic or associative neurons, and the spinal medulla itself is enabled to act as a unit.

Spinal Cord Centers.

The segments of gray matter in the medulla spinalis may be regarded as in a sense independent nerve centers. They are the immediate sources of the nerve energy which is discharged in skeletal muscles and but one step removed from the immediate source of the energy discharged in glands, blood-vessels, and viscera. The discharge of their energy may be brought about by:

(a) The arrival of nerve impressions through afferent nerves from the general periphery, skin, mucous membrane, etc.

(b) The arrival of nerve impulses which descend the medulla spinalis from the encephalon.

In the former instance the action which takes place in peripheral organs is said to be reflex; in the latter cerebral in origin. Muscle activities due to cerebral action arise from acts of volition and are termed voluntary; glandular and visceral activity when

influenced by cerebral neurons respond rather to emotional states than to the will.

Automatic or Autochthonic Action.

Some investigators have concluded that the spinal cord centers may respond, in the absence of all nerve stimuli either cerebral or peripheral in origin, to changes in the chemic composition of the blood and lymph surrounding the nerve cells. Such action has been termed "automatic" or "autochthonic."

It is to be doubted if such activity ever takes place. It is virtually impossible to exclude from a nerve center all the nerve fibres which might convey stimuli to it, and unless all are excluded and it is then demonstrated conclusively that the center is capable of the discharge of nerve impulses in response to chemical alterations in its immediate environment, the theory fails of proof.

As knowledge of the nervous system increases, the formerly narrow field ascribed to reflex action has been greatly widened; thus, muscle tonus, trophic tonus, and vascular tonus, once ascribed to a purely automatic action of cord centers, are now understood to be reflex, responsive to a rhythmic succession of impressions arising in the general periphery. It is highly probable that as the study of neurology advances **every** discharge of a nerve impulse may be properly ascribed to the arrival of a nerve impulse from somewhere. If this statement raises in the mind of the analyst the question as to the source of the first nerve impulse, it may be answered that for any human individual this is easily understood—the action even of pre-natal environment upon the body periphery is amply sufficient to start innumerable afferent impressions inward to the centers, in which they evoke responsive action. This responsive action, when it is expressed in a peripheral organ, excites activity which in turn stimulates the peripheral endings of afferent nerves and starts a new set of impressions centralward. The cycle of nerve activity, once initiated from the outside, is self-perpetuating.

However, this reply, while conclusive enough as regards any given human individual, fails to go back to first causes and explain the initiation of the first nerve impulse to occur in any form of living organism. Did external impressions bring about the first responsive action through a bit of protoplasm which, by that very act, began to be modified in structure into nerve tissue? Or did nerve tissue arise as a differentiation of protoplasm for the purpose of establishing communication between internal parts of a primitive

organism? In this event, whence came the initial stimulus? From some difference in potential between the two connected masses of protoplasm? We do not know.

Trophic Tonus.

If efferent nerves are divided it is observed that not only do the nerves themselves undergo degeneration below the point of section, but also that the muscles to which they are distributed undergo a degenerative change. This change is not the mere atrophy of disuse, in which there is loss of bulk and solidity in the muscle without change in its essential structure, but is more; it is an actual deterioration in the chemical composition of the muscle, a perversion of metabolism.

From this it has been decided that the nerve exerts a trophic influence over the muscle, and that the rhythmic discharge of nerve impulses in the muscle is essential to its metabolic integrity. This is not to imply that there are transmitted a special set of trophic stimuli, apart from the motor stimuli which activate a muscle. There is no evidence of the existence of any such special trophic impulses; rather it is believed that the impulses which excite the characteristic activity of the peripheral tissue at the same time, and as a necessary concomitant of such activity, control metabolism. Certainly there are no nerves whose sole function is trophic. The trophic function belongs alike to all efferent nerves and in a more indirect way to all afferent nerves. The latter, in some way not clearly understood, influence the trophic function, perhaps by carrying centralward a constant stream of afferent impressions which convey to the centers information as to the chemical state of the body. At any rate, section of afferent nerves often leads to serious trophic disturbances in the areas thus deprived of their afferent pathways.

The centers in the medulla spinalis appear to emit a regular succession of stimuli which, when discharged in the peripheral organs, tend to maintain in them a normal metabolic rate. To this regular discharge of stimuli having a trophic influence, as well as to the normal metabolic rate resulting, the term "trophic tonus" has been applied.

Vascular Tonus.

The maintenance of an average arterial pressure throughout the body appears to be due to the maintenance of the muscular

walls of the arterioles in a state of persistent, moderate contraction, due to the discharge within the muscle of a constant succession of nerve stimuli. These stimuli either arise in the cell groups in the medulla spinalis known as "vaso-motor centers" or in sympathetic ganglia controlled and directed by the vaso-motor centers—probably the former. The activity of these centers may be modified by a variety of conditions which will thus alter vascular tonus. Nerve impulses from anywhere in the body may influence vascular tonus. Toxins in the circulation and having a special affinity for nerve tissue produce a marked effect upon the contraction of blood-vessels. This fact has led some physiologists to conclude that the vascular tonus is maintained automatically, or autochthonically, and is always due to the chemical condition of the blood and lymph. This is probably not the case; the phenomenon is basically reflex, though there is no doubt that these centers react to the influence of adverse chemicals.

Muscle Tonus.

If a muscle is divided its two parts will shorten and withdraw from each other. When a muscle is at rest and attached at both ends, it is constantly in a state of slight tension. This contraction is brought about in the muscle by the discharge through its motor nerves of a rhythmic succession of moderate stimuli, none strong enough to induce a maximum contraction of the muscle but each producing a slight contraction. These follow each other at such short intervals that the muscle does not have time to relax between stimuli; thus a permanent, slight contraction is produced.

It has been demonstrated that the nerve impulses which govern muscle tonus are eight to twelve per second in number, and that they are aroused reflexly. The same conditions which interrupt the general reflex arc interrupt muscle tonus. Muscle tonus is increased by any factor which exaggerates the excitability of the reflex centers.

Reflex Action.

Reflex action has already been discussed somewhat. (See pages 258 and 261). The nerve cells in the medulla spinalis are capable of responding to stimuli from the periphery by generating and discharging nerve impulses which when transmitted to muscles excite contraction; in glands, secretion. In viscera and blood-vessels these impulses either excite or inhibit muscular artivity. To all such actions

which occur without the intervention either of sensation or volition the term "reflexes" is applied. Many such acts occur through the medulla oblongata and some of a similar character through the cerebellum.

Some writers have described three planes of action, volitional, instinctive, and reflex. Those bodily activities which are initiated and controlled by conscious acts of will are called volitional; those which seem to have arisen through race experience in relation to the outside world and to be performed without volition but under cerebral domination are called instinctive; those which are simply responses to peripheral stimuli are called reflex.

It is difficult to establish exact lines of demarcation between these types of nerve activity and therefore difficult to defend the classification although it is a convenient one at times. Under certain conditions acts which customarily belong to one group may appear in another. There is no distinct localization in the nerve system of these three types of action. True, the cerebral cortex seems to be the seat, and the only seat, of volition. But not all the cortex is concerned directly with volition and it is impossible strictly to delimit the volitional areas. We consider the protective action of the upper extremity which occurs when the front of the body is injured as being instinctive; yet such protective movements have been observed after decapitation and must have occurred wholly through the spinal cord segments and should probably be viewed as purely reflex.

Most reflex arcs involve much more nerve tissue than merely the simple mechanism which is held to be essential in all cases and which consists of a receptive end-organ, an afferent nerve, an emissive cell, an efferent nerve, and a responsive organ. The additional elements which complicate reflex action are not found at the periphery but within the central nerve system. They are interposed between the afferent neuron on the one hand and the efferent neuron on the other, and are known as intercalated neurons. In a reflex mechanism there may be one set of intercalated neurons passing between afferent and efferent groups of neurons or there may be several groups of intercalated neurons forming a chain. Furthermore, at any link in the chain; that is, at any point where two neurons make contact with each other, there may be a modification of the impulse or a retardation of its passage. Two neurons may act upon one in different and perhaps antagonistic manner.

The one may excite the next neuron in the chain and the other inhibit it. These factors make the study of reflex action far less simple than would be implied in the description of the simple mechanism.

Not the least important factor is the **storage** of impressions, the faculty possessed by nerve tissue of retaining the impression for a variable time and then responding to it. This faculty is the basis of memory and makes possible all association of ideas.

Conditions Governing the Reflexes.

It is possible for a stimulus applied to the peripheral end of a reflex arc to be so weak as not to evoke any response. The sensitiveness of the reflex arcs vary in different individuals and under different circumstances.

The influence of the upper neurons which descend to the cells of the spinal medulla from the cerebrum tends to inhibit reflex excitability and the degree to which this influence is exerted varies at times. It may be voluntarily increased, so that a group of cells in the cord is prevented entirely from responding to a stimulus to which it would ordinarily react. Conversely, an exercise of the will for that purpose may diminish the usual inhibitory influence of the upper neurons and thus bring about an increase in the excitability of the reflex center and an exaggeration of its response to peripheral stimuli.

Separation of the brain from the cord or any experimental or pathological interruption of the pyramidal tracts is followed by an increase in the reflex excitability of the cord below the level of the lesion.

The toxic action of certain drugs, notably strychnine, produces exaggeration of the reflexes rather by lessening the resistence to the passage of afferent impressions across the cord than by a direct excitation of efferent cells. So marked is this effect that even small doses of strychnine will cause marked tetanic contraction of all the skeletal muscles. Exclusion of all external stimuli greatly diminishes these contractions and increase of outside stimuli intensifies them.

The conditions which diminish or abolish reflex excitability are:

(a) Stimulation of certain brain areas.

(b) Stimulation of sensor nerves.

(c) Certain lesions of the medulla spinalis.

(d) Toxic action of drugs.

By experimentation upon frogs it has been found that stimulation in the region of the optic lobes results in inhibition of reflex excitability in the lower centers. Division of the frog brain just feetward of the optic lobes causes temporary inhibition due to the stimulation of those lobes incident to the operation, but this inhibition quickly disappears. It is believed that in this portion of the brain are centers possessing the power of inhibiting reflex activity and to some degree subordinate (*in man at least*) to the cortical motor centers.

If sensor nerves be stimulated to a degree which would ordinarily call forth a response and at the same time another distant sensor nerve be strongly stimulated, the response to the first may be delayed in time or completely inhibited. A similar phenomenon has been observed with regard to pain stimuli and their registration in consciousness. A moderate pain often ceases to be registered in the presence of more intense painful stimuli coming from another region of the body. The principle of counter-irritation sometimes employed in therapy takes this peculiarity of the nervous system into account.

The lesions of the medulla spinalis which diminish or abolish reflex irritability are especially those of the anterior horns. Atrophy of the cells of the anterior horn may completely destroy all reflexes in the affected area. Atrophy of ventral horn cells in a limited region does not, however, destroy the capability of cell groups above or below the lesion for responding to stimuli.

Certain drugs, such as chloroform, chloral, etc., appear to act upon the nerve cells themselves in such a way as to impair their activity and thus diminish their response to incoming stimuli.

Laws of Reflex Action.

Pfluger has set down five laws as follows:

1. **Law of Unilaterality.** If a mild irritation be applied to one or more sensory nerves, the movement will take place usually on the one side only, and that the side which is irritated.

2. **Law of Symmetry.** If the stimulation be sufficiently increased motor reaction is manifested not only by the irritated side but also in similar muscles on the opposite side of the body.

3. **Law of Intensity.** Reflex movements are usually more intense on the side of irritation; at times the movements of the opposite side equal them in intensity; but they are usually less pronounced.

4. **Law of Radiation.** If the excitation continues to increase it is propagated upward and reactions take place through centrifugal nerves coming from cord segments higher up.

5. **Law of Generalization.** When the irritation becomes very intense it is propagated in the medulla oblongata, which becomes a focus from which stimuli radiate to all parts of the cord, causing general contraction of all the muscles of the body.

These five laws of Pfluger, deduced from extensive experimentation, have been confirmed in substance by many subsequent investigators. There seems to be no exception, for instance, to the Law of Symmetry.

Overflow of Stimuli.

It has been pointed out that neurons communicate with each other only by means of their terminals and that there is no other way in which an excess of stimuli may be transferred from one neuron to another. A study of the phenomena of reflex action seems to lead to the conclusion that not all the terminals of each neuron are brought into play in the discharge of each stimulus passing through it. The extent to which the collaterals, for example, participate in the discharge may be due to the intensity of the stimulus.

A mild stimulation passes through the reflex arc by the simplest and most direct channels. It enters the cord by the afferent nerve, passes forward on the same side to the ventral horn, and excites the ventral horn cells to the discharge of energy. A stronger stimulus, entering by the same pathway and similarly exciting the ventral horn cells of the same side, will overflow, so to speak, through collaterals which cross in the commissure and reach ventral horn cells of the opposite side; in this way a bilateral response is evoked. The fact that the response on the opposite side is less marked than that on the irritated side suggests that only a lesser portion of the stimulus crosses the cord. It is as if water flowing through a channel had arisen to a level which would permit it to escape through an overflow channel, shallower than the main channel and acting as a spillway.

Propagation of the more intense stimulations upward through the cord, as stated in the Law of Radiation, occurs through intercalated intrinsic neurons which are connected both with afferent and efferent neurons. In most of the reflex arcs there are such intercalated neurons connecting the entering dorsal root fibres with the efferent nerve cells of the same segment and side. Others receive the afferent impression and in turn communicate it to several segments as in Fig. 94

It must be remembered that the same peripheral stimulation which evokes reflex action may also produce sensation, part of the stimulus passing to the brain by the long ascending branches of the dorsal roots while the remainder is disposed as above described.

Classification of Reflexes.

Among the multitude of reflexes used in the operation of the body there are some, concerned with the more superficial portions of the body, which are of special value in enabling an examiner to understand the nature and location of nerve lesions, because these reflexes are characteristically increased or diminished in certain pathologic conditions. They are divided into three groups:

1. The superficial or skin reflexes.
2. The deep or tendon reflexes.
3. The organ reflexes.

SUPERFICIAL REFLEXES

These are characterized by contraction of the underlying muscles when the skin is irritated, as by pricking, pinching, scratching, etc. The following are the most important of the superficial reflexes.

A. **Plantar Reflexes**, which consist of contractions of the muscles of the foot when the sole of the foot is stimulated, as by sharp stroking; they involve the integrity of the reflex arc through the sacral segments of the cord.

B. **Gluteal Reflex**, which consists of contraction of the glutei muscles when the skin over the buttock is stimulated; this reflex passes through the segments giving origin to the fourth and fifth lumbar nerves.

C. **Cremasteric Reflex,** which consists of a contraction of the cremaster muscle and consequent retraction of the testicle toward the abdominal ring when the skin on the inner side of the thigh is stimulated; it passes through the first and second lumbar segments.

D. **Abdominal Reflex,** which consists of contraction of the muscles of the abdomen when the skin on the side of the abdomen is gently scratched. It involves the integrity of the spinal cord segments from the eighth to the twelfth thoracic.

E. **Epigastric Reflex,** which is elicited by stimulating the skin between the fourth and sixth ribs; the response is a slight muscular contraction in the epigastric region. This reflex passes through the cord segments from fourth to seventh thoracic.

F. **Scapular Reflex,** which is a contraction of scapular muscles when the skin between the scapulae is stimulated. It is transmitted through the cord between the fifth cervical and third thoracic segments.

The superficial reflexes are normally present in health but are variable. Their absence or feebleness is not necessarily a symptom of disease but may indicate a low general irritability of the nervous system. They are abolished in disease of the gray matter of the cord and exaggerated in disease of the lateral columns and of certain parts of the cerebrum and also by abnormal excitation of the gray matter of the cord as in tetanus, strychnine poisoning, etc.

DEEP REFLEXES

The deep or tendon reflexes are of much value in the diagnosis of disease. They are more constant than the superficial reflexes and their modification has more significance.

These reflexes are elicited by a sharp tap on a tendon which is attached to a slightly extended muscle. Muscle tonus is a true reflex, in which a constant stream of afferent impressions is being carried from tendons and muscle-ends to the spinal cord and a resultant stream of efferent impulses is being carried to and discharged in the muscle. When the muscle is slightly extended the muscle tonus is naturally increased. If, now, the tendon be sharply tapped, the effect is to bring about a sudden increase in the extension of the muscle, with the consequent development of accentuated afferent stimuli; this, if the cord be normally excitable, induces an

accentuation of efferent impulses and a sharp contraction of the muscle producing a "jerk".

An appreciable interval of time elapses between the tap and the responsive contraction. This time is spread over the entire reflex mechanism but the greater part of it is used up in the transference of the stimulus within the cord. This period varies with the irritability of the cord. It is not possible to state a precise normal interval in which a tendon reflex must occur, but a little experience will enable the examiner to determine within reasonable limits whether a reflex is unduly rapid or unduly retarded. As a rule a too quick tendon reflex is also exaggerated in intensity and a long delayed response is also feeble.

The most important tendon reflexes are:

A. **The Patellar Reflex or Knee-jerk.** This consists of a contraction of the extensor muscles of the thigh when the ligamentum patellae is struck between the patella and the tibia. It is best obtained when the legs are hanging freely over the edge of the table. Or the patient may be seated with one leg crossed over the other.

The patellar reflex is generally present in health, being found in 98% of normal individuals. It is absent in locomotor ataxia and in destructive lesions of the anterior horns, sometimes in extreme neurasthenia. It is exaggerated in lateral sclerosis, in descending degenerations of the cord, and in some toxic states.

B. **Ankle-jerk.** This is elicited by striking the tendo calcaneus (*tendo Achilles*) while the extensor muscles of the leg (*gastrocnemius and soleus*) are on a stretch. A quick extension of the foot takes place.

C. **Ankle Clonus.** This consists of a succession of rhythmic contractions of the gastrocnemius muscle, varying in frequency from six to ten per second. It is elicited by making pressure upward upon the sole of the foot so as to suddenly and strongly flex the foot at the ankle, thus putting the tendo calcaneus and the gastrocnemius muscle upon a stretch. Within limits, the rhythmic contractions, if present at all, will continue as long as the pressure on the foot is maintained.

Ankle clonus is never present in health but is found in all conditions which markedly exaggerate the normal reflexes through the

lower portion of the cord. It is usually strongly marked in cases of lateral sclerosis.

D. **The Babinski Reflex, or toe reflex.** This is normally present in infants in whom the pyramidal tracts have not become myelinized, but should disappear after a few months. It is a pronounced dorsiflexion of the great toe when the sole of the foot is stroked and depends upon the activity of the lower centers in the cord uninfluenced by cerebral control. When that control is established the Babinski reflex changes to a "grasping reflex" in which the great toe is flexed ventrally. The Babinski reflex persists in children several years old who are victims of incomplete development of the central nervous system and is associated with the spastic paralyses of the infantile type. Occasionally it recurs in adults who develop lesions of the lateral funiculus of the cord.

A **peroneal reflex** and a **wrist reflex** are also present in lateral sclerosis and in the late rigidity of some hemiplegias.

ORGAN REFLEXES

Many organ reflexes operate not through the medulla spinalis but through the ganglia of the sympathetic, while others pass through the cord centers. The sympathetic ganglia, in this connection, may be considered as projected portions of the spinal cord, sharing its functions.

Owing to their depth and to the difficulty in experimentally inducing organ reflexes, few of them are of service in diagnosis. Since the genito-urinary center is located in the lumbar region of the cord, an increase, diminution, or abolition of the genito-urinary reflexes sometimes indicates cord disease. The more important organic reflexes will be taken up later in the consideration of Special Nerve Mechanisms.

THE MEDULLA SPINALIS AS A CONDUCTOR

In addition to serving as a series of centers for reflex action, the spinal cord serves as an important conductor of nerve impulses. This conduction is carried on chiefly by the white fibres, which are massed around the gray core, and consists of:

A. **Intersegmental conduction.**

B. **Spino-encephalic conduction.**

C. **Encephalo-spinal conduction.**

Intersegmental, or Associative.

Conduction is the conveyance of stimuli from one cord segment to another. It is sometimes called "intrinsic" conduction because the fibres which perform this duty do not leave the spinal medulla and are therefore intrinsic to it.

The spinal cord is composed of a series of physiologic segments, each partially independent of the others and related to one pair of spinal nerves and through them to one definite segment of the body. For the harmonious co-operation of these spinal segments it is essential that they be linked together by avenues of communication. For this purpose intrinsic cells are scattered thickly throughout the gray matter, especially at its periphery. Their axons emerge into the white matter and ascend or descend for a variable distance in the fasciculi proprii, adjacent to the gray matter. Some of these axons are commissural, crossing the mid-line to associate the two halves of the cord. Each segment is commonly in association with several adjacent segments both above and below, but especially above. More marked co-operative reactions are developed in segments above a stimulated area than below it.

The great variability of the reflexes depends largely on the complexity of arrangement and communications of these intrinsic neurons and upon their power either to hasten, retard, or store the impulses passing through them.

Spino-encephalic Conduction.

Sensory impressions arising in the general periphery, that is, in nerve endings in the skin, mucous membranes, muscles, and viscera are transmitted to the medulla spinalis by the dorsal root fibres. Many of these afferent impressions are used up in evoking reflex action, but many others are transmitted through the cord, either directly or indirectly, to the cerebral cortex. In the cortex they are received by specialized nerve cells and by them translated into sensations. These sensations may be classified as **special sensation,** such as pain, touch, pressure, and temperature, and **general sensations,** arising out of the condition of the body but attributable to no particular area, such as hunger, thirst, well-being, fatigue, and sex.

Sensor Decussations.

All the sensory impressions entering the cord for transmission to the encephalon appear to cross from the side on which they enter

to the opposite side before reaching their ultimate destination in the cerebral cortex. Not all decussate at the same level. Some of the fibres, particularly those conveying the pain and temperature senses, together with part at least of the tactile fibres, decussate soon after entering the cord. Others, particularly those which ascend in the fasciculus gracilis and fasciculus cuneatus carrying the muscular and tendinous sense, ascend without crossing until they reach the medulla oblongata, where they undergo a decussation known as the **upper sensor decussation,** in contrast to the crossing at various levels of the cord which is called the **lower sensor decussation.** Still a few fibres contained in the ventral spinocerebellar fasciculus decussate as high as the mid-brain.

It is plain that each half of the encephalon is in sensory communication with the opposite half of the body; and that the decussation for touch, pain, and temperature is below that for the muscular and tendinous sense. Experimental section of one lateral half of the cord as a rule abolishes all forms of cutaneous sensibility below the injury and on the opposite side, while the muscle sense is abolished on the side of the lesion.

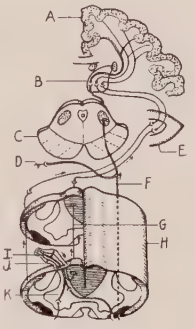

Fig. 97.

Sensory Pathways and Decussations. AA, Cortex; B, Thalamus; C, Cerebral Peduncles; D, Sensory Cranial Nerves; E, Cerebellum; F, Direct Sensory Pathway; G, Posterior Column; H, Section of Spinal Cord; I, Dorsal Root Ganglion Cells; J, Dorsal Root; K, Sensory Branch to Motor Cells of Ventral Horn.

Special Pathways.

There has been much, and still is some difference of opinion as to the precise pathways followed by the different types of sensation in their transit through the cord. The best recent opinion seems to be that the muscle sense traverses the fasciculus cuneatus and fasciculus gracilis as far as the gracile and cuneate nuclei of the medulla, where the pathway divides, part of the impressions passing to the cerebellum by way of the internal arcuate fibres and the inferior peduncle, while the remainder continue upward to the cerebrum by way of the medial lemniscus. The muscle sense also reaches the dorsal spinocerebellar fasciculus by way of Clark's column. Some of the entering dorsal root fibres terminate in Clark's column, which is a column of gray cells situated near the base of the dorsal horn; from these cells new axons arise which ascend at first obliquely outward and then upward in the dorsal spinocerebellar tract. This tract reaches the cerebellum by way of the inferior peduncle and probably decussates in the cerebellum before terminating.

Touch is carried both by the gracile and cuneate fasciculi and by the spinothalamic tract.

Pain and temperature impressions travel in the spinothalamic tracts and probably also in the ventral spinocerebellar at least.

The exact pathways by which the general sensations of hunger, thirst, etc., traverse the cord are unknown. They have been provisionally located in the gray matter and in the white matter of the lateral column. No evidence on the subject is really conclusive.

Direct and Indirect Sensor Pathways.

A subject in a way more closely related to the physiology of the brain than to that of the cord is that of the division of the sensory pathway into a direct and an indirect portion.

The direct sensory pathway ascends the cord by the gracile and cuneate fasciculi and the spinothalamic tracts. In the former instance the ascending dorsal root fibres continue up the cord to the medulla where they terminate in the nucleus gracilis and nucleus cuneatus, where new axons arise to ascend in the fillet, or lemniscus. These in most instances terminate in nuclei in the optic thalamus, whence arise new neurons to complete the pathway to the postcentral area of the cerebral cortex. The spinothalamic fibres, arising in the gray matter of the cord, ascend to the thalamus, where new neurons complete the pathway to the cortex. This pathway from cord to cortex is called the direct sensory pathway.

The indirect sensory pathway involves the cerebellum and gives to that organ the impressions upon which is based co-ordination of reflexes and of the synergetic action of muscles, especially those concerned in the maintenance of equilibrium. As might be inferred, the impressions from muscles and tendons and many of the tactile impressions are needed by the cerebellum and therefore travel by the indirect pathway. In the cord, their routes are by the posterior column, and by the dorsal and ventral spinocerebellar tracts. Those of the posterior column leave the direct pathway at the gracile and cuneate nuclei to travel by the internal arcuate fibres and inferior peduncles to the cerebellum. Those of the dorsal spinocerebellar fasciculus also pass through the inferior peduncle; those of the ventral spinocerebellar tract go as high as the mid-brain before turning back through the superior peduncle to the cerebellum.

The indirect pathway for sensations is completed by the passage from cerebellum to cerebrum of further afferent fibres which

convey to the cortex part at least of the impressions derived through the indirect pathway.

Encephalo-Spinal Conduction.

Definite pathways have been observed by which the cerebrum exercises control over the motor centers in the cord. This control is not manifest at birth; the activities of the newborn are almost purely reflex and not psychic or volitional; they are the functions necessary for the maintenance of organic life, such as swallowing, breathing, sucking, etc., but are not purposive in relation to the child's environment.

Within a short time volitional activities begin to appear and the reflex activity of the cord is modified and regulated. This occurs when the descending encephalo-spinal fibres develop their myelin sheaths and become fully capable of functioning. The cord centers, on the contrary, are fully developed and physiologically capable at birth.

The view is advanced that the fibres which arise in the pre-central area of the cerebral cortex and terminate by an arborization around the dendrites of the ventral horn cells of the cord are really commissural in function, connecting and associating these two portions of the central nerve system.

By experiment and by investigation of the effects of pathological lesions it has been determined that the fibres are the efferent pathways for the transmission of motor or volitional impulses from the cerebral cortex to the medulla spinalis. The tract as a whole was called "the pyramidal tract" by Charcot because the cortical area in which the fibres originate is four-sided and the fibres converge as they approach the internal capsule, giving to the mass between the cortex and the internal capsule somewhat the shape of a pyramid with a truncated apex at the capsule.

The area of origin is located in the convolutions just anterior to the central, or Rolandic, fissure, the pre-central area. Thence the fibres descend through the corona radiata, traverse the genu and the anterior two-thirds of the posterior limb of the internal capsule, pass through the middle three-fifths of the crusta of the cerebral peduncle, cross in the ventral part of the pons from above downward and, in the medulla oblongata, undergo incomplete decussation. Thence the **direct motor pathway** is divided into two parts.

The larger part, consisting of from two-thirds to nine-tenths of the fibres (*percentage variable*) decussate at the pyramidal decussation (*upper motor decussation*) in the lower half of the medulla. This portion sweeps backward, enters the lateral column of the medulla, and descends in the lateral column of the cord as the **lateral cerebrospinal fasciculus.** It diminishes in size as it descends but is visible down to the lower segments; its diminution is due to the fact that at each successive level of the cord it gives off fibres which terminate in relation with the ventral horn cells.

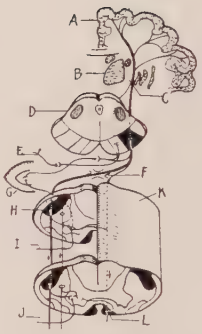

Fig. 98.

Motor Pathways and Decussations. A, Cortex; B, Thalamus; C, Internal Capsule; D, Crus Cerebri; E, Motor Cranial Nerves; F, Upper Motor Decussation (Decussation of the Pyramids); G, Cerebellum; H, Fasciculus Cerebrospinalis Lateralis (Crossed Pyramidal Tract); I, J, Ventral Roots of Spinal Nerves; K, Section of Cord; L, Fasciculus Cerebrospinalis Ventralis (Direct Pyramidal Tract).

The lesser portion of the pyramidal tract after reaching the medulla continues through it undecussated and descends adjacent to the ventromedian fissure of the cord as the **ventral cerebrospinal fasciculus.** It too diminishes as it descends, by giving off successive fibre bundles which cross in the anterior white commissure and come into relation with the ventral horn cells of the opposite side. This tract is distinct only as far down as the lower thoracic segments, though some of its fibres undoubtedly reach the lumbar and sacral segments.

An older terminology referred to these tracts as the **direct pyramidal tract** (*ventral*) and the **crossed pyramidal tract** (*lateral*). These terms are somewhat misleading inasmuch as the two tracts, taken together, constitute the direct motor pathway, while the indirect motor pathway does not include either. The terms ventral and lateral cerebrospinal fasciculi are more suitable.

Section of the pyramidal tract in the brain or of the anterior and lateral columns of the cord is invariably followed by complete loss of all power of voluntary motion below the lesion on one side only; division below the decussation in the medulla abolishes voluntary motion on the side of the lesion; division above the medulla, on the opposite side. Such division is also followed by exaggeration of the reflexes on the paralyzed side, which indicates that these tracts normally exert an inhibitory influence over the reflex irritability of the cord.

Stimulation, by electricity, of the peripheral ends of the cut fibres at the site of the section induces muscular actions of a character usually voluntary.

Electrical excitation of the cortical cells of origin of the pyramidal tract gives rise to characteristically voluntary movements of the skeletal muscles of the opposite side of the body; destruction of the cortical cells produces paralysis of the same muscles.

Since the cell bodies preside over the nutrition of the axons, it follows that separation of axons from their cells causes degeneration of the axons. It has been found that lesions in any part of the pyramidal tract cause degeneration of the fibres downward; this has been considered as evidence that the pathway is descending and that the nerve impulses in this tract are conveyed downward and never upward. All methods of investigation point conclusively to the fact that these fibres transmit volitional impulses from the cerebral cortex to the spinal cord.

The Indirect Motor Pathway.

There is another descending pathway by which the cortex of the cerebrum is related to the ventral horn cells of the cord, indirectly, through the intermediation of the cerebellum. This is called the **indirect motor pathway.** Its uppermost neurons originate in the cortex of the frontal, temporal, and occipital lobes, pass through both the anterior and posterior portions of the internal capsule, occupy the margins of the crusta of the cerebral peduncle, and in the pons terminate in relation with the cells of the nuclei pontis. Here new axons arise to pass to the cerebellum by way of the middle peduncles; they terminate in the cerebellum and a third set of neurons continue the pathway by traversing the superior peduncle to the mid-brain, where they end in relation to the cells of the red nucleus. In the red nucleus arise a fourth set of neurons which descend the cord as the **rubrospinal fasciculus** and terminate in successive groups in relation to the ventral horns.* The decussation of the rubrospinal tract takes place just after it arises from the red nucleus; the right half of the cerebellum is brought into communication with the left half of the cord and vice versa.

It is probable that the vestibulospinal and possibly also the tectospinal fasciculus is part of the indirect motor pathway.

The ventral horn cells to which the indirect motor pathway conveys stimuli are the same to which the direct motor pathway conveys voluntary impulses. Thus the last link is the same in both pathways. Impulses converge, as it were, upon these ventral horn

*It is possible that the fibres of the two motor pathways which descend the cord are connected with the ventral horn cells by intercalated neurons.

cells from two sources. They may conflict with each other and the stronger stimulus prevail. They may coincide and co-operate. A series of complicated muscular actions may be initiated by the will and thereafter continued and completed through the indirect pathway.

There is the greatest difficulty in distinguishing clearly between voluntary and involuntary actions and between the relative influence of the two portions of the brain upon the spinal cord centers. When it is remembered that these same centers are also centers for purely reflex action and may respond to peripheral stimuli without the intervention of any portion of the brain, and that there exist in the medulla oblongata and in the optic thalamus certain cell groups called "centers" which exercise a general influence over the subsidiary centers in the cord, it is easy to perceive the hopelessness of attempting to disentangle every action of the spinal cord from the others.

Despite the undoubted fact that the cord is segmented, albeit not so simply and perfectly as in lower forms of life, the actions which take place through it are more often systematic than segmental. That is, they bring into play various groups of cells whose association for this functional purpose lies in the fact that they send axons to organs which are functioning as a system, rather than in anatomic contiguity. Many of these systematic functions of the cord will be discussed later in connection with the nerve mechanisms which control the important body functions.

FUNCTIONS OF THE ENCEPHALON

The encephalon, developed from the anterior end of the neural tube, is a continuation upward of the neural axis which is represented below the magnum foramen by the medulla spinalis. And it is more than that. That portion of the encephalon immediately surrounding the ventricular system does indeed resemble the cord in function, though in a less regular and more complex fashion. The cerebellum, somewhat detached from the brain-stem, like an excrescence upon a stalk, has no direct connections with peripheral nerves but is made up entirely of neurons, or parts of neurons, belonging to the intercalated system. The larger part of the cerebrum, an aggregation of intercalated neurons of comparatively recent development (*neopallium*) is characterized by a group of functions, some like and others unlike those of the cord. In studying the physiology of the various brain organs the student should review their anatomy. Gross function in the brain is largely a matter of anatomical arrangement. It should be remembered also that the entire brain is composed of neurons or parts of neurons some portion of which extend beyond the brain, and that at base the function of each neuron is like to that of all others; to generate nerve impulses in its neurocyte and to transmit them through its axon to a termination at which the impulses are given off either to the dendrites of other neurons or to peripheral structures.

In the encephalon there arise some neurons, constituting the efferent roots of cranial nerves, which pass uninterrupted to end in skeletal muscles. These are a small minority out of the total of encephalic neurons. By far the greater majority terminate in relation with other neurons and act upon them. It follows that a great part of brain physiology consists of the study of the interaction of neurons upon each other; all of this, however, is conditioned upon the connection of these sets of neurons by other projecting neurons with the entire body.

Functions of the Medulla Oblongata.

The medulla, like the spinal cord, is composed of gray matter disposed internally adjacent to the fourth ventricle (*headward expansion of the central canal*) and of white matter, generally arranged external to the gray. The arrangement, however, is considerably modified as compared with the cord. (See page 35).

The functions of the medulla are two-fold; it serves as a series of centers for reflex action, and as a conducting pathway for nerve impulses passing to and from the encephalon.

As a reflex center, or series of centers, the medulla is less simply segmented than the cord; indeed, its segmentation is almost imperceptible except by analogy. There are attached to the medulla and the pons Varolii, which is its upward continuation, the last eight pairs of cranial nerves. The efferent components of these eight pairs consist of part of the fifth, all of the sixth, part of the seventh, ninth, and tenth, and all the eleventh and twelfth nerves. They arise in nuclei of cells analagous to the nuclei of origin of the motor spinal nerves except as to regularity of arrangement. In general these nuclei are clustered close to the floor of the fourth ventricle although in the medulla they occupy a more dorsal situation than in the cord. The cells of these nuclei generate motor impulses which are propagated outward (*centrifugally*) over the efferent nerve fibres and are discharged in skeletal muscle where they give rise to contractions.

The afferent components of the last eight cranial nerves are part of the fifth, part of the seventh, all of the eighth, part of the ninth, and part of the tenth. These afferent fibres arise in the cells of ganglia situated outside the brain and on the course of the nerves. They enter the brain-stem and terminate in relation with afferent or receptive nuclei of termination from which new neurons arise to convey to some part of the encephalon the impressions derived from skin, mucous membranes, muscles, or special sense organs. These nuclei of termination are situated for the most part in close relation to the floor of the fourth ventricle.

In addition to the nuclei directly related to cranial nerves there are in the medulla numerous other gray masses whose connections and functions are less easily ascertainable. These may be gathered into a considerable mass, as in the olives, or scattered in small gray clusters as in the formato reticularis.

Nerve Centers.

The term "nerve center" as used in connection with the medulla, does not necessarily mean a group of nerve cells in close anatomical juxtaposition. It means rather a group of cells which act together for the accomplishment of some systematic function. These may be closely grouped together or they may be at some distance from each other and connected by associative fibres. In

some cases two similar groups of cells on opposite sides of the median line may be so joined by commissural fibres as to act together under certain circumstances, and these are then known as a "center." Portions of the nuclei of origin of several cranial nerves may be included in the mechanism known as a center, inasmuch as their joint action is essential to the proper performance of some systematic function such as deglutition. The precise anatomical description of these centers is impossible in the present state of our knowledge. Yet we know that they exist and that some of them exert an influence over similar, but subordinate centers in the spinal cord or sympathetic ganglia which serves to co-ordinate the activity of those centers.

Centers in Medulla and Pons. The medulla and pons contain a number of such centers, probably more than are definitely known. Those whose existence is quite certain are:

1. A general **cardiac** center, composed of two portions, right and left, intimately associated across the median line. Each half has a double influence; (a) accelerator and (b) inhibitor, upon the action of the heart.

2. A **vaso-motor** center, which governs the caliber of blood-vessels throughout the body by presiding over the subsidiary centers of vaso-motor control in the medulla spinalis.

3. A **respiratory** center, which co-ordinates the actions of the many muscles concerned in respiration.

4. A **mastication** center, which excites to activity and co-ordinates the muscles of mastication.

5. A **deglutition** center, which regulates the muscular activities required for the transfer of food from the mouth to the stomach.

6. An **articulation** center governing the muscular actions necessary to articulate speech.

7. A **perspiratory** center, which regulates the secretion of perspiration by the perspiratory glands throughout the body, by controlling subsidiary spinal cord centers.

8. A **salivary** center, to control the secretion of saliva.

9. A **vomiting** center, which under special circumstances assumes temporary control of many muscles ordinarily influenced by other centers, and regulates the complicated activity which occurs in vomiting.

10. An **expression** center, which co-ordinates the muscles of the face concerned in expression.

In addition to these there is probably a center which regulates glycogen formation (*so-called "diabetic center"*), and others. A question arises as to whether there exists in the medulla a special **thermic,** or heat-regulating center, maintaining an influence over both the vaso-motor and perspiratory centers. There is insufficient evidence to support the conclusion that such a special center exists; it is probable that the vaso-motor and perspiratory centers are acted upon by the same influences, such as the temperature of the blood, toxins, etc., so that they act in harmony at times, but separately.

Hind-Brain Sympathetic Fibres. The medulla and pons, like the thoracic region of the spinal cord, give off in the trunks of their attached cranial nerves certain fibres whose function is secretory, vaso-motor, and viscero-motor. These are pre-ganglionic in character and their impulses ultimately reach glands, blood-vessels and involuntary muscle. Such fibres are found in the fifth, seventh, ninth, and tenth nerves, and reach the ophthalmic, sphenopalatine, otic, and submaxillary ganglia and the cardiac and coeliac plexuses by pathways already described.

Medulla and Pons as Conducting Pathways.

As conducting pathways the medulla and pons contain white fibres which may be divided into four groups; afferent, efferent, associative, and commissural.

The afferent tracts in general occupy the dorsal portion. At the lower level of the medulla enter the fasciculus gracilis and fasciculus cuneatus, conveying touch impressions and those from muscles and tendons. These fasciculi are interrupted at the nucleus gracilis and nucleus cuneatus, where their stimuli are transferred to two sets of new neurons, the one set to continue upward in the lemniscus, decussating a little above the nuclei, to pass through the dorsum of the pons and crura cerebri, and to terminate in the optic thalamus, whence new neurons complete the direct sensory pathway to the post-central area of the cerebral cortex; the other to pass by way of the internal arcuate fibres and inferior peduncles to the cerebellum.

In the lateral column the spinocerebellar and spinothalamic fasciculi enter at the lower level. The dorsal spinocerebellar tract turns backward and reaches the cerebellum through the inferior peduncle, carrying from Clark's column of the cord impressions of

muscular and tendinous sense and touch, upon which the cerebellum will base its equilibratory control. The ventral spinocerebellar fasciculus splits into two parts, one of which joins the inferior peduncle, the other continuing upward through the pons to the mid-brain, where it turns backward to reach the cerebellum through the superior peduncle. The spinothalamic tracts continue upward at the edge of the medial lemniscus and reach the thalamus, to which they convey impressions chiefly of pain and temperature from the homolateral and contralateral sides of the cord.

The principal **efferent** tracts are two in number in the pons and three in the medulla. The rubrospinal fasciculus descends through pons and medulla from the red nucleus of the mid-brain. The destination of its fibres is the ventral gray matter of the opposite side of the cord and their function is to convey to these cells motor impulses of an involuntary character.

The **pyramidal** tract, undivided in the pons but largely decussating in the medulla and there dividing into two tracts, contains voluntary motor fibres belonging to the cerebral projection system. Its axons are derived from the cortical cells of the pre-central area; they terminate in relation to ventral horn cells of the opposite side of the cord and some of them in relation with the motor cranial nerve nuclei in pons and medulla. They exert over the nerve-cells of the lower neurons both an influence inhibitory to reflex action and a control of voluntary motion in skeletal muscles.

The **associative fibres** are numerous fibres passing between various parts of the gray matter of the same side. The most important of the bundles is the medial longitudinal bundle, whose fibres serve to associate the various cranial nerve nuclei; it lies in the dorsal portion close to the floor of the fourth ventricle. Other associative fibres are so numerous and so intricately arranged as to defy description.

The chief group of **commissural** fibres are those which make up the middle peduncles. They arise in the cerebellar cortex, enter the pons by the middle peduncles and make up a large portion of its transverse layers. They decussate in the pons and then sweep by the opposite middle peduncle to the opposite hemisphere of the cerebellum. Other fibres of the middle peduncles arise in the nuclei pontis; they are commissural in a sense because they are a link in the pathway which unites the cerebral cortex with the opposite half of the cerebellum; they form part of the indirect motor pathway.

MID-BRAIN FUNCTIONS

The gray matter of the mid-brain is found in a layer which surrounds the cerebral aqueduct and in the corpora quadrigemina (*colliculi*). The former gives origin to the third and fourth cranial nerves. The nuclei of these nerves emit impulses which when transmitted to the muscles of the eye excite them to contraction. The superior colliculi are cell-stations interposed in the visual pathway. They also give off fibres which descend as the tectospinal tract and are concerned with visual reflexes. The inferior colliculi are cell-stations interposed in the acoustic pathway. They receive impressions derived from the internal ear by way of the lateral lemniscus and in turn transmit them to the auditory centers in the cortex of the temporal lobe. They are doubtless also concerned with auditory reflexes.

The **crura cerebri** act as conducting paths for the great sensory and motor tracts on their way to and from the cerebrum. The crusta of the crus cerebri gives passage to the pyramidal tract and to the frontopontine and temporopontine tracts. The tegmentum cruris transmits the ascending medial and lateral lemnisci, the ventral spinocerebellar fasciculus and the spinothalamic, as well as the medial longitudinal bundle, which associates the nuclei of origin of the third and fourth cranial nerves with the lower cranial nerve nuclei.

The crusta and tegmentum of the crus cerebri are divided by a layer of gray matter, the substantia nigra. It is believed that some reflex actions take place through this layer, but this fact has not been definitely established. It is certain, however, that the gray matter beneath the floor of the cerebral aqueduct is the center for reflex actions connected with the eye such as closure of the lids, contraction of the sphincter pupillae, convergence of the eyes, etc. The afferent pathway for these reflexes is by way of the optic nerve and the efferent pathway by way of the oculomotor and trochlear nerves.

FUNCTIONS OF THE CEREBRUM

From the physiologic standpoint the cerebrum may be divided into the **basal ganglia** and the **neopallium**; the basal ganglia comprise the optic thalamus, geniculate bodies, corpus striatum (*caudate and lintiform nuclei*), and the amygdala; neopallium is the name given to the mantle of white matter surfaced by the gray cortex which makes up the bulk of the hemispheres.

The Optic Thalami.

These are essentially ganglionic masses, although many projection fibres enter and leave the thalami and they are traversed by innumerable associative fibres. Each thalamus appears to consist not of a single ganglion but of several, each of which is in special relation to one of the important nerve paths.

The anterior part of the thalamus contains nuclei of termination which receive many of the ascending fibres of the medial lemniscus. From these cells new axons arise to pass to the cortex. These nuclei are interposed cell-stations in the general sensory pathway which conveys tactile and muscle impressions.

The spinothalamic fasciculi convey pain and temperature impressions which are apparently received by special cell groups in the thalami.

The pulvinar of the thalamus is the seat of termination of many fibres of the optic tract. New fibres constituting the **optic radiations of Gratiolet** arise in these cells and pass through the posterior limb of the internal capsule to spread out to the so-called "visual area" of the occipital cortex. The thalamus is therefore an interposed cell station in the visual pathway.

Whether or not the thalamus contains cell groups interposed in the acoustic pathway is still in doubt.

The thalamus receives fibres from the frontal, temporal, parietal, and occipital areas of the cortex, some of which appear to give rise in the thalamus to impulses which descend through the medial longitudinal fasciculus to the motor nuclei of cranial nerves, especially the seventh, and to control those facial expressions which arise from or reflect emotional states.

The relation of the thalamus with the expression of emotion is not entirely clear, but there appears to be such a relation, as well as a connection with many motor nerve nuclei both cranial and spinal. Certain lesions of the thalamus may produce hemiathetosis.

A general center for the regulation of the body temperature has been provisionally located in the thalamus. It seems to operate by regulation of the distribution of blood; it probably exerts an influence over the vaso-motor center in the medulla and the subordinate centers in the cord.

The Lateral Geniculate Body.

Like the pulvinar of the optic thalamus and the superior colliculus, receives some of the fibres of the optic tract and acts as one of the lower visual centers. It gives off axons which pass by the optic radiations to the occipital cortex.

The Medial Geniculate Body.

Like the inferior colliculus, is similarly interposed in the acoustic pathway; it is a cell station which helps to unite the lateral lemniscus with the cortex of the temporo-sphenoidal lobe.

The functions of the corpora striata and amygdala are somewhat obscure. It is known that fibres pass in both directions between the striate bodies and the cortex and also between these bodies and the optic thalamus, and that the caudate and lentiform nuclei are connected to each other by fibre tracts. It is difficult to state precisely what functions these fibres serve. Destruction of the corpus striatum of one side in an animal leads to paralysis of the skeletal muscles of the opposite side and stimulation of the corpus striatum produces convulsive contractions of the same muscles; this suggests association with the pyramidal tract, but anatomic relation with that tract might account for some or all of the effects. Some physiologists believe that if the gray matter of the corpus striatum alone is destroyed the resulting paralysis is merely transient.

White Matter of the Cerebrum.

The white matter which makes up the bulk of the hemispheres is composed of medullated nerve fibres. These are divided into three sets:

A. **Projection fibres,** both afferent and efferent, which unite the cerebral cortex with more or less distant parts of the brain-stem.

B. **Commissural fibres,** which cross the median line to unite parts of the two hemispheres.

C. **Associative,** or **arcuate fibres,** which are confined each fibre to its own hemisphere and unite different cortical areas with each other.

The **projection fibres** which are efferent in function arise in the cells of the cortex in all its lobes, and converge toward the medial portion of the base of the brain; that arrangement of fibres between the cortex and the internal capsule is known as the **corona radiata.**

The efferent projection fibres pass compactly through the internal capsule and descend through the crusta of the crus cerebri, after which they are variously disposed. The frontopontine tract and the temporo-occipitopontine terminate in relation with the nuclei pontis; they are parts of the indirect motor pathway and convey impulses which will ultimately be transformed into involuntary contractions of skeletal muscles. The pyramidal tract fibres, after passing through the crus cerebri and the pons, divide in the medulla into the ventral and lateral cerebrospinal fasciculi and their axons terminate in relation to the ventral horn cells of the opposite side of the cord. They convey impulses which will ultimately be expressed as voluntary contractions of skeletal muscles. On its way through the crus cerebri this tract gives upper neuron fibres to the nuclei of origin of the oculomotor and trochlear nerves and in the pons and medulla to the motor nuclei of the fifth, sixth, seventh, ninth, tenth, eleventh, and twelfth. Their relation to these nuclei is precisely the same as the relation of the longer fibres to the ventral horn cells.

The afferent projection fibres, consisting of the cortical extension of the sensory pathways, enter the base of the cerebrum near the inner side and diverge through the corona radiata to various cortical areas. Many of these are interrupted in the thalamus and the thalamo-cortical fibres belong to the projection fibre group, as do those which unite the cortex with the other basal ganglia.

The **commissural fibres** intermingle with the projection fibres in every lobe. They are gathered as they cross the median line into three main groups, the corpus callosum, the anterior commissure, and the posterior commissure.

The **association,** or arcuate, fibres, are both long and short. Long fibres unite distant lobes; short fibres unite adjacent gyri and some are intragyral. The association fibres are so numerous and varied in their connections as to permit a multitude of different associations between parts of the cortex. They make possible almost infinite combinations of brain cells for the purpose of co-operation.

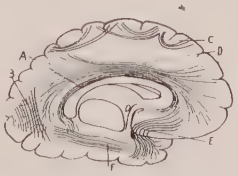

Fig. 99. Schema of Arcuate Fibres, Cingulum, and Fasciculus Longitudinalis.

A, Cingulum; B, Dorsal Fasciculus; C, Short Arcuate Fibres; D, Superior Longitudinad Fasciculus; E, Uncinate Fasciculus; F, Inferior Longitudinal Striae.

The **internal capsule,** chiefly important from a pathological standpoint in connection with hemiplegia, is a layer of projection fibres lying between the optic thalamus and caudate

nucleus medially and the lentiform nucleus laterally. As seen in transverse section it presents a medially directed convexity known as the **genu.** Through the genu pass those pyramidal tract fibres which reach the nuclei of origin of the motor cranial nerves; they are called **genicular fibres** and convey voluntary motor impulses to the muscles of the head, face, and tongue. The anterior two-thirds of the posterior, or retrolenticular, limb of the internal capsule contains the remainder of the voluntary motor fibres; i. e., those to the trunk and limbs.

The frontopontine tract traverses the anterior limb of the capsule in front of the genu. The sensory projection fibres which come up by way of the lemniscus occupy a position in the posterior limb posterior to the motor tract. This occipital portion of the posterior limb also gives transit to the optic and acoustic radiations.

The pathological importance of the internal capsule is due to the fact that in its immediate vicinity are located the lenticulostriate arteries, which terminal arteries are the most direct branches of the middle cerebral artery, so that they are most subject to strain by abrupt alterations of the blood pressure and most liable to become the site of lodgment of emboli. Hemorrhages from these vessels, as well as embolism or thrombosis situated in them, are prone to destroy the conductivity of some of the nerve fibres traversing the capsule and thus produce paralysis. The precise distribution of the paralysis may indicate the portion of the capsule affected by the lesion.

Functions of the Cerebral Cortex.

The cerebral cortex is the most highly specialized portion of the nervous system. Its structure has been described on page 98. It is impossible to estimate with accuracy the number of gray cells contained in the entire cortex; Meynert estimates 612 millions; Thompson 9,000 millions.

The functions of the cerebrum as a whole include all the manifestations of sensation, cognition, feeling, and volition. Most of these are centered in the cortex which thus becomes the seat of consciousness and of those forms of life known as psychic. In other words, all the phenomena of mind are expressed through the activity of the cells of the cerebral cortex.

Not only is this true but the cortex exercises a directing control over what may be termed "activities of relation" and a less

potent but none the less important influence even over the vegetative life of the body.

Relation of Cortex to Lower Centers.

Into the cortex pour a constant stream of afferent impressions derived from all parts of the body, from the cutaneous surface, the muscles and tendons, the special sense organs. Probably none of these reach the cortex without suffering interruption somewhere by the termination of the peripheral sensory neuron (*lower neuron*) and the transfer of its impression to a higher cortically directed neuron (*upper neuron*). Few of the sensory pathways are so simple as to be made up of only two neurons placed end to end; in most of them the lowest neuron in the chain is connected to the uppermost by one or several intercalated neurons. By this means impressions from several lower neurons may be brought to bear upon a single upper neuron.

Not all the afferent stimulus developed in the peripheral sensory nerve reaches the cerebral cortex. Part of it is given off, by a splitting of the end of the axon, to nerve cells along the route and may serve them as a basis for reflex action. Collaterals from the afferent axons may carry off part of the stimulus to each of several motor cells in the cord or ganglia.

Furthermore, the afferent impression may be retarded, perhaps stored, in the cell station which intervenes between the lower neuron and the upper. Thus the total of impressions reaching the sensorium is somewhat less than the total developed at the periphery, but is nevertheless representative at all times of the entire body and completely informative as to the state, relation, and activity of the body.

On the efferent side of the cycle of sensori-motor activity, the most efficient agent in the production of motor activity (*including vaso-motor and secretory activity*) is, of course, the ganglionic cell group, either in the cord or in the sympathetic, which is most closely connected with the innervated tissue. Contraction of a skeletal muscle is directly excited by nerve stimuli sent out by ventral horn cells; changes in the caliber of blood-vessels and in the secretory activity of glands are immediately excited by the nerve energy discharged by the sympathetic ganglia, which may be considered as detached and projected portions of the medullary gray. It must be remembered that the actual energy utilized in these tissue actions is generated in the tissues themselves and is not furnished by the nerves;

the function of the nerves is merely to bring about **release** of tissue energy and to direct it.

Above the primary centers which begin the last link in the peripheral chain are higher centers, situated in the spinal axis (*including the medulla as a superior prolongation of the cord*), which direct and co-ordinate the activities of the primary centers. Above these is superadded the cortical structure which exercises over all the lesser centers a **directing** control. In the case of the vegetative functions this control is vague and obscure; it is entirely involuntary and strictly limited. Animal life is capable of persistence after the destruction of the cortex, though less efficiently. Over the functions of relation the cortical control is definite and assertive.

The cortex does not actually command in detail every muscular contraction which exhibits a volitional character. Instead it makes use of lower nerve mechanisms which are trained and experienced in the carrying out of the details of station, locomotion, prehension, etc. The cortex initiates these movements, starts the co-ordinating mechanisms in cerebellum, medulla, and cord into an habitual series of stimuli and reactions of a reflex character, and stops the series at will; it furnishes the directing force.

In order to accomplish this direction and to make intelligent use of the multitude of sensory impressions received, the cortex contains many cells not directly devoted either to the reception of impressions or the sending out of motor impulses.

These cells compare and associate impressions and develop **ideas** and **concepts**; they store up impressions for future use and this is **memory**. Ideation and memory, like conscious sensation and volition, are peculiarly the property of the cortex. After destruction of the cortex in an animal, there may be physical manifestations of pain but no memory of pain.

Recollection.

Not the least of the cerebral powers is that of recalling, by an act of will, impressions which have been stored up as memory. By this process the individual is enabled to make use of past experience as a basis for present action. Not all memories can be recalled. There is no doubt that there exist in every human brain a multitude of stored-up impressions which are beyond the reach of consciousness under ordinary circumstances. To the vast reservoir of information thus hidden beyond the waking mind, the term

"subconscious" has been given. Study of the phenomena of the subconscious belongs rather to phychology than to physiology. It is sufficient to state here that no definite brain areas can be set aside as the habitat exclusively of the subconscious; that the threshhold between conscious and unconscious shifts at times and under changing circumstances; and that part at least of the memory content of the subconscious must be present at birth and presiding over those functions which are well performed at birth and without earth experience, such as respiration, deglutition, etc.

Localization of Cortical Function.

Physiological experiments in animals and observation of the effects of pathological conditions in man have enabled physiologists to ascribe rather precise functions to certain definite areas of the brain surface, particularly those concerned with sensation and motion. There still remain, however, unmapped areas, doubtless because of the difficulty of experimenting with the purely psychic functions which are not developed in animals as in man and which disappear with loss of consciousness.

As a matter of fact, cortical areas are not usually exclusively devoted to a single specific function. Functional spheres of influence overlap and intermingle to some extent. A given group of cells may belong to one functional system for one purpose and become a part of a different association for the accomplishment of a different end. A map of the surface of the brain to indicate functional localization must of necessity be vague and inexact; it can only furnish approximate and general information.

Motor Area.

Most certain of all is the location of the cortical area from which develop voluntary motor impulses. This region is located in front of the central, or Rolandic, fissure, in the frontal convolutions. The centers which control the leg and foot are on the medial aspect of the hemisphere on the wall of the median longitudinal fissure. Upon the lateral surface of the hemisphere, the area which controls the trunk is highest, then that for the upper extremity; lowest is the center for the head and face and closely associated with this and located in the third left frontal convolution is the center for articulate speech.

Sensory Area.

Immediately behind the central fissure, and in the parietal lobe, lies a general sensory area which corresponds closely in ar-

rangement with the motor area, from which it is separated by the fissure. On the medial aspect terminate fibres conveying impressions of touch and muscle sense from the leg and foot. On the lateral aspect the trunk, arm, head and face are represented. Posterior to the general sensory area and occupying the upper gyri of the temporo-sphenoidal lobe is the center for audition.

The cortical center for reception of the sense of smell is located on the medial aspect of the hemisphere in the region known as the hippocampus.

The cortical center for vision is situated in the occipital lobe, where it occupies part of the medial and part of the inferior surface. This area is connected to the superior colliculus by cortico-collicular fibres, and to the pulvinar of the optic thalamus and the lateral geniculate body by the optic radiations (*centripetal fibres*).

Bilateral Representation.

All the sensory and motor centers of the cortex are duplicated in the two hemispheres. Owing to the complete decussation which takes place in both pathways the right side of the brain contains the centers which are directly connected with the left side of the body and vice versa. A curious functional phenomenon occurs in this connection. It is usual that only one group of centers, the left in right-handed people, the right in left-handed people, do most of the work of directing bodily activities.

Homologous cortical areas are intimately connected across the mid-line by commissural fibres. It appears that the labor of which both the right and left motor groups, for example, are capable is by common consent habitually performed by the one group which by earliest initiative or experience takes precedence over the other.

The disparity in development and activity between the two sides is less marked in the case of the motor centers than in the cell groups devoted chiefly to the storage of memories and the association of ideas. If, for example, a lesion in the brain interrupts the integrity of the fibres proceeding from the left motor area a right hemiplegia will result; this paralysis will be, and will remain, reasonably complete; it is impossible for the right motor area to assume direction of the skeletal muscles of the right side except through the left motor area. If, on the other hand, a lesion interrupt the connections of the left speech memory center, word memory

may be completely lost but in time a new word memory may be developed by education of the right, and hitherto inactive center.

The slightly preponderant size of the left cerebral hemisphere as compared to the right, in right-handed people, is enough to require an appreciably larger cranial vault on that side. This cranial asymmetry, which is rather common than otherwise, suggests that the developement of the bony cage is secondary to that of its nervous contents.

Broca's Area.

The third left frontal convolution was first discovered by Broca to be the cortical center for articulate speech and for word memories. It is therefore named "Broca's Area."

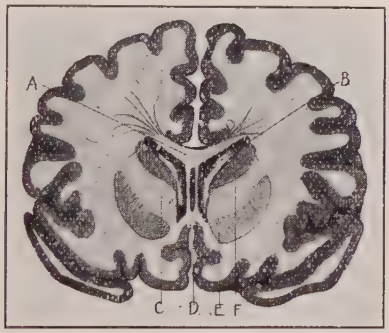

Fig. 100. Coronal Section Through Cerebrum.
A, Corpus Callosum; B, Lateral Ventricle; C, Internal Capsule; D, Cavum Septi Pellucidi; E, Lentiform Nucleus; F, Caudate Nucleus.

FUNCTIONS OF THE CEREBELLUM

It is certain that the cerebellum gives rise to no volitional impulses and is not the seat of any conscious sensation. Its connections with the brain-stem are such, however, as to bring into it sensory impressions, tactile, muscular, vestibular, acoustic, and visual, which constitute complete information at all times as to the state, position, and relation of the body. The superior peduncles bring to the cerebellum impulses from the cerebrum; others descend by the frontopontine and temporo-occipitopontine tracts to the nuclei pontis and thence traverse the middle peduncles to the cerebellum. The inferior peduncles convey a host of impressions from the spinal cord and medulla, originally derived from the general periphery, and also part of the vestibular pathway from the semicircular canals of the ear. Some of the fibres of the middle pedun-

cles are commissural, uniting the two cerebellar hemispheres across the median line.

The cerebellum is provided with an efferent pathway by way of the superior peduncle, red nucleus, and rubrospinal fasciculus by which it can and does communicate with the nuclei of origin of all the motor spinal nerves and some, at least, of the cranial. As has been stated, there is a double upper neuron influence brought to bear upon these centers; that from the cerebrum to control volitional motions, and that from the cerebellum to control involuntary motions.

The sole function of the cerebellum seems to be the direction and co-ordination of the muscular activities which have to do with station and equilibrium. The mere act of standing requires the co-operation of almost all the muscles of the body. To maintain the body in the upright position its center of gravity must be made to fall within the polygon represented by the margins of the feet. Since the limbs are jointed, the joints must be held fixed by contraction of the flexors and extensors in measured opposition to each other.

Every change of attitude complicates this problem of securing proper muscular contraction to maintain balance. Walking is a process involving a constant shifting and restoration of balance. All these multitudinous adjustments of muscle tension are governed by the cerebellum in accordance with the constantly arriving afferent stimuli which apprise it of progress already made. Manifestly, the impressions from muscles and tendons which pass by the lateral funiculus of the cord and the inferior peduncle are of extreme importance to the cerebellum.

It has been observed that destruction of the semicircular canals in an animal produces almost identical effects with destruction or isolation of the cerebellum; inability to maintain equilibrium and convulsive rotary movements in response to very mild peripheral stimulation. This argues that the pathway between the semicircular canals and the cerebellum must be one of the chief avenues of afferent stimuli upon which the latter depends.

The activities of the cerebellum have been described by some writers as "automatic". They proceed without volitional interference or control except as the cerebrum may initiate an act such as walking or running and then relinquish it at its inception for the cerebellum to continue until commanded to stop. In all proba-

bility the equilibratory functions of the cerebellum are reflex in character, but a high and complicated order of reflexes carried on in systematic and organized fashion by cell groups which have become habituated to them.

In man, most cerebellar actions have to be learned slowly and laboriously before that organ can perform them without the aid of the will. In some of the lower animals the ability to stand and walk is present practically at birth; in such cases it appears that the cerebellar cells have been "educated" prenatally, as a part of racial heredity.

Goll located the seat of parental love in the cerebellum but there is no evidence as to any specific pathway for its expression.

It has been noted that in the species of animals having the greatest necessity for equilibrium, as in the birds, the cerebellum is relatively more developed than, for example, in the reptiles, which have almost no cerebellum at all.

Little has been done toward dissociating the functions of the different parts of the cerebellum; its function must as yet be ascribed to the entire organ rather than to any part.

FUNCTIONS OF THE SYMPATHETIC SYSTEM

As has already been stated in previous chapters, the common function of all neurons is to generate and convey nerve stimuli to the organs to which the neurons are distributed. The effect of these stimuli is to excite the stimulated organ to the performance of its characteristic function. Nerve functions are therefore classified according to distribution and connections.

The term "sympathetic system" is applied to that portion of the peripheral nerve system which is distributed to the non-striated muscle tissue and secretor epithelium of the body and because these tissues enter largely into the structure of blood-vessels, viscera, and glands, the functions of the sympathetic system are described as vasomotor, visceromotor, pilomotor, and secretory.

Augmentation and Inhibition.

Most of the organs reached by the sympathetic are supplied with two sets of fibres, the function of one of which is to augment or increase the activity of the organ and of the other to inhibit or retard it. Thus there are **excito-glandular** and **inhibito-glandular** fibres; **vaso-constrictor** and **vaso-dilator** fibres; **viscero-motor** and **viscero-inhibitor** fibres.

As a rule, the two sets of fibres travel in the same main nerve trunks, but there are notable exceptions, as in the case of the innervation of the heart, to be presently described. The two sets of fibres bring to bear upon the organ antagonistic influences just as the pyramidal tract fibres and the afferent sensory fibres exert opposing influences upon the reflex excitability of the ventral horn cells of the cord, the one to inhibit their activity and the other to excite it. Preponderance at any given moment of the one influence or the other upon the peripheral organ determines whether its activity will increase or diminish.

Vascular tonus and visceral tonus are maintained by a nice equilibrium between the two sets of nerves. The rhythm of the heart action is similarly maintained by an equilibrium between accelerator impulses sent out over the sympathetic and inhibitor impulses which travel over the vagus nerve.

It is highly probable that the difference in effect between the accelerator and inhibitor impulses in any organ is due not to differences in the stimuli themselves, or in the structure of the nerve

fibres which carry them, but rather to special modifications of the nerve endings or of the transition substance which intervenes between the nerve terminal and the essential substance of the organ. There is still room for much investigation along this line, but the weight of evidence favors this explanation.

It is entirely clear, however, that the centers from which are emitted impulses which will be expressed respectively as inhibition or augmentation are anatomically distinct. In some instances they are removed from each other by a considerable distance; in others they lie so close together as to be really one center in two divisions.

Relation of Sympathetic to Cerebrospinal System.

The ganglia of the sympathetic bear the same relation to the blood-vessels, viscera, glands, and hair muscles as do the ventral horn nuclei of the cord to the skeletal muscles; that is, a single neuron connects the ganglion with the periphery and the ganglion cell is the direct or immediate source of the nerve energy discharged in the peripheral tissue. Likewise, the peripheral, or lower, sympathetic neuron presides over the nutrition of the cells it reaches just as the spino-peripheral neuron governs the nutrition of the skeletal muscle.

The sympathetic ganglia are connected with the spinal nerves by pre-ganglionic and post-ganglionic fibres. The former arise in small cells at the base of the ventral horn of the cord, leave the spinal nerve shortly after its emergence from the intervertebral foramen, and join the sympathetic. Some terminate in the nearest ganglion, some pass through the nearest to terminate in a more distant one. All the efferent pre-ganglionic fibres influence the ganglia in much the same way as the descending pyramidal tract fibres influence ventral horn cells; they regulate their reflex activity and at the same time impart to them impulses to action (*involuntary*). The ganglia may be regarded as of the same order as the medullary gray matter but drawn out toward the periphery by the exigencies of development. The spino-ganglionic neurons are similar to the cortico-spinal.

The post-ganglionic fibres arise in the ganglion cells and join the spinal nerves to be distributed with them to the blood-vessels and glands in their respective zones. Others (*afferent*) undoubtedly enter the spinal ganglia, where, by the intermediation of the cells of Dogiel, they impart sensations to the dorsal root fibres. The sympathetic system has no direct sensory pathway to the cortex of the brain and ordinarily does not give rise to sensations. That is,

the ordinary vegetative actions of the viscera are accomplished without arousing consciousness. Under exceptional circumstances the sensorium becomes aware of visceral sensation, especially of pain, through the transference of afferent impressions from the sympathetic to the cerebrospinal system; in this event the sensation is usually interpreted as having arisen in the muscles or integument overlying the viscus, because it is the habit of the brain, receiving pain impressions over that nerve pathway, to associate them with their usual source.

The sympathetic system possesses a limited independence from the cerebrospinal system, but not more independence than that of the lower cerebrospinal neurons from the upper. If the pre-ganglionic fibres are severed the sympathetic speedily becomes incapable of normal action; some reflex excitability is maintained for a time, and the ganglia are still able to preside over the nutrition of the innervated parts. Co-ordination is lost, however, and one writer describes the picture of a sympathetic cut off from its spinal connections as "a nervous system gone mad."

The functions of the sympathetic, owing to the difficulty of experimentation, have generally been studied *en bloc*, and are commonly described in four groups; cranial, cervical, thoracic, and lumbar.

Functions of the Cephalic Ganglia.

The ganglia situated in the head have been described in connection with the trigeminal nerve, from which all receive sensory roots. Each also receives a motor root from a cranial nerve. Each gives off sympathetic fibres to control non-striated muscle tissue and secretor epithelium in its vicinity. The sensory and motor roots bear the same relation to these ganglia as do the pre-ganglionic spinal nerve fibres to the remaining ganglia.

The **ciliary, or ophthalmic, ganglion,** situated behind the eyeball, receives preganglionic fibres by a short root from the inferior division of the oculomotor nerve; these end by arborizing around the ganglion cells. Stimulation of the preganglionic fibres produces contraction of the circular fibres of the iris with a diminution in the size of the pupil, and contraction of the ciliary muscle with accommodation of the eye for near vision. Division of the preganglionic fibres gives rise to the opposite effect; that is, to dilatation of the pupil and loss of accommodation.

Postganglionic fibres arise in the superior cervical ganglion and reach the ciliary ganglion by way of the internal carotid nerve and cavernous plexus; they pass through the ganglion to the blood-vessels of the iris and retina to which they are constrictor in function. Sensory fibres from the ophthalmic division of the fifth nerve pass through the ganglion to the cornea, which they endow with sensation.

The **spheno-palatine** (*Meckel's*) ganglion is situated in the upper part of the pterygo-palatine fossa. It derives preganglionic fibres from the seventh, or facial, nerve by way of the great petrossal. Sensory fibres from the maxillary division of the fifth nerve pass through it. It receives postganglionic fibres derived from the superior cervical ganglion.

Its branches are distributed to the glands and blood-vessels of the nasal and oral regions. Stimulation of the ganglion brings about dilatation of blood-vessels and increase in secretion through this region. Stimulation of the superior cervical ganglion often causes abrupt constriction of the blood-vessels in the locality innervated by the spheno-palatine ganglion. This may mean that the fibres derived from the superior cervical ganglion pass through the spheno-palatine uninterrupted and are distributed as vaso-constrictors in the same area where the spheno-palatine branches act as vaso-dilators.

The **otic** ganglion lies just below the foramen ovale and in close relation to the mandibular division of the fifth nerve. Its preganglionic fibres are derived from the ninth nerve by way of Jacobson's nerve and the small petrosal. Postganglionic fibres are distributed to the parotid gland by way of the auriculo-temporal branch of the fifth nerve, and to the blood-vessels of the mucous membranes of the lower lip, cheek, and gums. Stimulation of these nerves in any part of their course induces dilatation of blood-vessels and increase of secretion in the innervated area.

The **submaxillary** and **sublingual** ganglia lie near the glands for which they are named and distribute postganglionic fibres to these glands and surrounding blood-vessels. Preganglionic fibres reach these ganglia from the facial nerve by way of the chorda tympani. Inasmuch as stimulation of the chorda tympani or of the ganglia themselves gives rise to increased secretion of saliva and to vascular dilatation, it is concluded that the chorda tympani carries vaso-dilator and secretor fibres. Vasco-constrictor, and

some secretor fibres, reach these ganglia, and the otic, from the superior cervical ganglion.

Functions of Cervical Sympathetic.

Stimulation of the superior cervical ganglion produces a variety of effects: The action of the heart is accelerated; the pupil dilates; the blood-vessels of the skin and mucous membranes in various parts of the head and face are constricted; there is increase of the secretion from the submaxillary gland and the perspiratory and mucous glands, and, in the dog, erection of the hairs of various parts of the head and neck and dilatation of the blood-vessels of the lips, gums, and hard palate. Division of the cervical sympathetic cord below the superior cervical ganglion produces the opposite of the above effects and stimulation of the divided cord restores the former group.

It thus appears that the superior cervical ganglion is an important cell station interposed between the spinal cord and the blood-vessels and glands of a large region, as well as the heart and the eye. It has been demonstrated that preganglionic fibres which reach this ganglion leave the upper four thoracic spinal nerves by their white rami, enter the gangliated cord, and ascend through the intermediate ganglia to reach and terminate in the superior cervical ganglion. Other similar fibres, however, end in the inferior and middle cervical ganglia.

While stimulation of the preganglionic fibres will produce all the above described effects, it has been noted that direct stimulation of the ganglion itself produces them more positively. The ganglion seems to be composed of numerous cell groups, the exact anatomic limits of which cannot be clearly defined but which, if separately stimulated, will produce some of the above effects in limited regions. No doubt the functions of the cells of this ganglion would be found to be very strictly localized were it possible to stimulate at will each single group without affecting others. It should be remembered that this ganglion represents a coalescence of four original ganglia into one, the four corresponding to the upper four cervical nerves but connecting, like the rest of the gangliated cord, with the thoraco-lumbar region of the cord.

The middle and inferior cervical ganglia also distribute branches to the heart and in addition supply the blood-vessels of the pharynx, larynx, thyroid gland, and neck.

The centers in the cord from which all these ganglia derive impulses seem to be in a state of constant activity, which is probably reflex in character. Thus the heart receives through this mechanism a constant succession of accelerator stimuli, which are kept in balance by the constant inhibiting influence of the vagus; the pupil is maintained in a persistent state of normal contraction by the measured opposition of contractile impulses passing through the oculomotor nerve and dilator impulses traversing the cervical sympathetic and its cephalic extensions. This "tonic" activity of sympathetic centers has sometimes been described, though erroneously, as autochthonic; that is, due to the chemical interaction between the nerve cells and the surrounding blood and lymph.

Functions of the Thoracic Sympathetic.

The functions of the thoracic sympathetic, like those of the cervical, are the control of secretion and of blood-vessels, both dilatation and constriction. From all the thoracic ganglia gray rami are given to adjacent spinal nerves which carry vasomotor and secretory fibres to the cutaneous and subcutaneous vessels and to the glands of the skin in the regions to which the spinal nerves are distributed. In addition, the upper thoracic ganglia send fibres into the brachial plexus for the blood-vessels and glands of the upper extremity. Pilo-motor fibres are similarly distributed.

Cutaneous nerves to the lower extremities pass by way of the lower lumbar and upper sacral ganglia and enter the spinal nerves as gray rami. Their preganglionic fibres are derived from the spinal nerves from the twelfth thoracic to the second or third lumbar. It will be observed that the vascular and secretory distribution of postganglionic fibres from the thoracic (*or thoraco-lumbar*) sympathetic, divides itself into two groups, an upper group which sweeps upward, and a lower group, which sweeps downward; intermediate between these both in position and direction are the fibres which accompany the intercostal nerves.

A similar divergence is seen in the distribution of vaso-motor and secretory nerves to the interior of the body. The upper thoracic ganglia give accelerator fibres to the heart (*many of which ascend to the stellate and to the cervical ganglia*) and vasomotor fibres to the lung and esophagus. The lower group of thoracic ganglia give origin to the **three splanchnic nerves,** which bear a marked resemblance in origin, direction, and distribution, to the three cervical cardiac nerves. The division between what may be termed the

thoracic and the abdominal distribution of the thoracic sympathetic is not an equal one, the upper four ganglia contributing the former and the lower eight the latter. Indeed it is probable that most of the distribution of the fourth thoracic ganglion is sub-diaphragmatic, stimulation of that ganglion or of the white ramus entering it seeming to affect the liver more than any other organ.

The **splanchnic nerves** contain both preganglionic and postganglionic fibres. The former are derived by the white rami from the spinal nerves from the fourth to the eleventh inclusive; they pass through the adjacent ganglia and follow the trunks of the splanchnic nerves to the ganglia of the coeliac and renal plexuses, from which short postganglionic fibres complete the pathway. The postganglionic fibres contained in these nerves are derived from the lower eight thoracic ganglia.

Stimulation of the great splanchnic produces inhibition of the intestinal movements, a marked primary contraction of the intestinal blood-vessels and of other viscera, followed by dilatation. At the same time there is a primary increase followed by a decrease of blood-pressure throughout the body. The capacity of the abdominal blood-vessels for dilatation is such that at the extreme of such dilatation they are capable of containing five-sixths of the volume of blood ordinarily present in the entire body; their general constriction would therefore naturally produce a marked increase of general blood pressure and their general dilatation a marked decrease. This physiologic fact becomes of extreme importance in the study of the pathology of fevers and will be later referred to in that connection. Division of the great splanchnic is followed by reversal of the phenomena of stimulation, and stimulation of the divided nerve restores the originally described phenomena. Stimulation of the central end of the divided nerve produces a sharp general rise in blood-pressure which indicates that the great splanchnic contains afferent fibres which stimulate the general vaso-motor center. This bears out the theory that the persistent activity of that center is reflex in character.

Functions of Coeliac Plexus and Its Subdivisions.

While the coeliac plexus receives fibres from the vagus nerves, its principal source is the great splanchnic. Ganglia in the coeliac plexua and in its subpleuxses receive preganglionic fibres from the spinal nerves and give off postganglionic fibres to the blood-vessels and to the abdominal viscera; these fibres are vaso-constrictor and

vaso-dilator, viscero-motor and viscero-inhibitor, and secretory, in function. These functions are common to all the subplexuses of the coeliac and the precise distribution of the branches of each plexus having been determined it is not difficult to estimate its general function. There are, however, certain special pathways which will be separately described.

Functions of the Lumbo-Sacral Sympathetic.

The lumbar and sacral ganglia receive preganglionic fibres from the lower thoracic and upper lumbar nerves, some of which descend in the gangliated cord for some distance before terminating. The visceral branches from the second and third sacral nerves, which resemble the white rami, apparently pass through the adjacent ganglia into the hypogastric plexus and there terminate in ganglia placed in close juxtaposition to the pelvic viscera which they innervate.

Postganglionic fibres given off by the lumbar and sacral ganglia reach the inferior mesenteric ganglion and, through the hypogastric plexus, the pelvic viscera. They are vaso-constrictor and vaso-dilator, viscero-motor and viscero-inhibitor, and secretory in function. The hypogastric plexus also supplies fibres possessing these functions to the external genitalia. In addition to the above the lumbar and sacral ganglia give off gray rami to the adjacent spinal nerves, which convey impulses which control the blood-vessels of the lower extremities, their cutaneous glands, and the pilomotor function.

Summary of Relation.

It has been shown that every function of the body involving nutrition, growth, repair, and reproduction is performed under the direction of a nerve mechanism the peripheral portion of which belongs to the sympathetic system; that each of these mechanisms has centers in the central axis which, if they do not directly furnish the energy which activates the tissues in the performance of their functions, at least govern the distribution and discharge of that energy; and that every portion of the sympathetic is so closely connected with the central axis of which it was originally a part that disturbances of the latter are invariably disturbing to the former. Further, any impairment of the integrity of the connections between the cerebrospinal system and the sympathetic will at once be followed either by loss or aberration of sympathetic functions within the zone of distribution of the interrupted pathway.

SPECIAL NERVE MECHANISMS

By virtue of the associative neurons which link together the various cell groups of the central nerve system it is brought about that a given neuron may, at different times and under different circumstances, associate itself with different other neuron groups for special functional purposes. For example, the nerves which control the larynx in phonation may also be brought into play for its protection during deglutition or to maintain it in proper position for respiration; some of the same nerves may act in that unusual combination of reflexes known as a cough. All these functions involve the larynx in some way. Instead of a particular and separate set of nerves for each of the functions in which that organ may participate, it is arranged that within the central system the different nerve cell groups may change their associations—may be called into action in different groupings and combinations. This arrangement makes far greater economy in nerve tissue.

Such a grouping of nerves for the accomplishment of a common purpose is spoken of as a "nerve mechanism." The term is physiologic rather than anatomic. While there is, of course, at the moment of performance of a function a very definite anatomic pathway through which that function is regulated, the next instant may see a slight shifting of function and a consequent shifting of nerve action to a different anatomic pathway. So intricate are the modifications of the many bodily functions that it is only possible to describe in a general way the pathways through which rather general functions are controlled. Even so much of allocation of function becomes extremely important when physiology is changed to pathology (*morbid physiology*) by lesions interrupting nerve pathways.

A brief outline of the nerve paths through which the more important functions are regulated follows. It is presumed in each case that the student is already familiar with the anatomy of the body organs and the general physiology of the function mentioned, so that discussion may be centered chiefly on nervous control.

Nerve Mechanism of Movement.

The human body performs molar motions by means of the contractions of its skeletal muscles, which are attached to bones and

utilize them as levers. These skeletal muscles are capable of contracting when excited by the arrival of nerve impulses through efferent nerves; at the same time they, and their tendons, are possessed of the terminals of afferent nerves which carry contralward impressions as to the state and position of the muscles.

All skeletal muscles are innervated by medullated nerve fibres arising in cells within the central axis, brain and spinal cord. The neuron which passes directly from brain or cord to the muscle is known as the **lower motor neuron;** it presides over the nutrition of the muscle and at the same time conveys to it the impulses to contraction which maintain its tonus and those which excite special contractions.

Muscles rarely act singly; they contract in groups, several muscles supplementing each other's action while others offer an antagonistic and balancing contraction. This co-ordination is brought about by the union within the central axis of various nerve centers by associative neurons, or by the simultaneous regulation of various centers by neurons of a higher order.

All efferent stimuli which reach skeletal muscles come through the lower neurons. Some of these induce voluntary action while others induce involuntary action. The use of the lower neurons alike for the subservience of these two types of nerve action is due to the fact that two different upper neuron influences are brought to bear upon the cell bodies of the lower neurons. These are (a) the direct motor pathway from cerebral cortex to lower neuron nuclei, either with or without the intervention of intercalated neurons, and (b) the indirect motor pathway, from cerebral cortex to cerebellum to mid-brain to lower neuron nuclei, also either with or without the intervention of intercalated neurons. These two influences may act separately or at the same time, in which latter case they are antagonistic and partially cancel each other, or harmonious and mutually augmentor.

Reflex activity may take place through the lower neurons without involving either motor pathway from the brain, but this, with the exception of the reflexes which produce muscle tonus, is uncommon. Most of the reflexes, while the energy used is generated in the lower neuron nuclei, are controlled and co-ordinated by the cerebellum through the indirect motor pathway.

Afferent pathways correspond with the efferent pathways for regulation of motion and are a necessary half of an "open cycle"

for motor activity. That is to say, every reflex contraction is preceded by an afferent stimulus. Each contraction in turn affects afferent nerve terminals so as to start another stimulus centralward, which in turn excites another motor impulse. Thus, so long as the motor impulses are properly expressed each brings about the production of a new stimulus which will excite its successor. A continuous cycle of nerve energy is thus generated and maintained through the lower neurons, which is interrupted only by the fact that action must supervene between each efferent and the consequent afferent stimulus; it is therefore called an "open cycle" to distinguish it from the similar but "closed" cycle which operates through the sympathetic nerve system for the regulation of vegetative life.

The reflexes in muscles are abolished if either the motor or sensory fibres are destroyed or interrupted. If the afferent pathway is interrupted above the level of its connection with the efferent cells, as in some lesions of the dorsal column of the cord, sensation is abolished but motion persists. If the efferent pathway is interrupted above the lower neurons (*in brain or lateral column of cord*) voluntary motion is lost but involuntary motion of a reflex character persists and is exaggerated because of the removal of the inhibiting influence of the upper neurons.

NERVE MECHANISM OF DIGESTION

The digestive apparatus includes the entire alimentary canal and its appendages or accessory organs, the teeth, tongue, salivary glands, the gastric and intestinal glands, the liver, the pancreas, etc. Manifestly, in order that the activities of all these parts may be co-ordinated and properly timed, an extensive nervous mechanism is required. Such a mechanism is provided by making use, not perhaps under a single directing center, but under several which co-operate with each other, of the motor and secretory nerves which are distributed to the parts of the digestive apparatus. Some of these nerves serve the purpose of digestion only, except in unusual circumstances; others, such as the nerves to the tongue, are frequently made to act as parts of other nerve mechanisms for other functional purposes.

Since the process of digestion is long drawn out in time, and may be conveniently subdivided into a number of included processes each of which is brought about through the action of its own nerve mechanism, it is convenient to study these mechanisms separately.

Prehension.

The act of grasping and conveying food to the mouth is, strictly speaking, not a part of digestion but a necessary preliminary to it. In man, this is accomplished by the use of the hands in motions which are initiated by acts of will but continued and carried out through co-ordinated reflexes presided over by the cerebellum.

Mastication.

This function requires the co-operation of many muscles. It is presided over by a masticatory center in the medulla oblongata beneath the floor of the fourth ventricle. This center is usually excited to initial activity by an act of will but thereafter continues to function by responding to afferent impressions which continue to be brought in to it from the mouth so long as food remains there. The masticatory center communicates with the efferent nuclei of the mandibular division of the fifth nerve, the hypoglossal nerve, and the facial nerve, and these nerves make up the efferent part of the reflex pathway of mastication. The afferent nerves involved are the lingual branch of the fifth nerve and the glossopharyngeal; the former, a general sense nerve from the tongue, also conveys taste fibres to the chorda tympani; the latter contains both touch and taste fibres, the taste fibres from the posterior third of the tongue and adjacent surfaces.

The center in the medulla not only generates the impulses which excite the masticatory muscles to contraction but also co-ordinates them so that they may be directed to the accomplishment of a specific purpose. Thus the use of muscles in the act of biting differs considerably from their use in the act of grinding food. We may be conscious of the intent to do the one or the other but not of the precise muscular relations required for either.

Insalivation.

Closely related to mastication and synchronous with it, occurs a secretion by the parotid, submaxillary, and sublingual glands, of saliva which is poured into the mouth and mixed with the food. It contains a digestive element, **ptyalin**, which converts starch into sugar.

For the performance of their secretory function the salivary glands appear to require both secretory and vaso-motor nerve action. Each gland is supplied with these two sets of nerves, both post-ganglionic fibres derived from nearby ganglia. The parotid gland

receives fibres from the otic and superior cervical ganglia, the submaxillary and sublingual glands from the ganglia bearing their names and from the superior cervical ganglion. Preganglionic fibres reach these ganglia through the upper thoracic spinal nerves (*to superior cervical ganglion*) and through the fifth, and ninth cranial nerves.

Within the central axis these various efferent nerves are coordinated by the action of a center located in the medulla oblongata beneath the floor of the fourth ventricle and known as the "salivatory center." To this center come impressions derived through the fifth and ninth nerves (*including the chorda tympani with the fifth*) which serve as a basis for the reflex activity of the center.

Insalivation is purely reflex. It cannot be initiated at will, although it may be aroused by purely psychic states, such as imagination of food. The exact pathway by which psychic states influence the secretion and discharge of saliva are not known. As might be expected, the salivatory center is in close juxtaposition to the masticatory center, with which it most closely co-operates.

Deglutition.

This is that part of digestion by which food is transferred from the mouth to the stomach. It involves the action of many muscles, not simultaneously but sequentially; these muscles are made to act in proper sequence by the control of a deglutitory center in the medulla oblongata, beneath the floor of the fourth ventricle.

The action of the tongue begins the act of swallowing; this is continued by the contraction in turn of the superior, middle, and inferior pharyngeal constrictors and then by the contraction, in a wave from above downward, of the esophageal musculature. At the proper time there must be relaxation of the cardiac orifice of the stomach, which is ordinarily in a state of tonic contraction. Simultaneously with the pushing of the bolus of food to the back of the mouth by the tongue, there occurs closure of the glottis, to prevent the invasion of food into the respiratory tract through the larynx; at the same time respiration is momentarily checked by fixation of the thoracic respiratory muscles.

With the exception that the initiation of the act of swallowing may be either voluntary or reflex, all parts of this function are reflex in character. The afferent stimuli are brought about by the entrance of food into the upper pharynx and the pathway by which

they reach the medullary center is by way of the glossopharyngeal and vagus nerves in all probability. The efferent pathway involves use of the mandibular division of the fifth nerve, the facial, the hypoglossal, and motor elements of the glossopharyngeal and vagus. To what extent postganglionic fibres from the sympathetic enter into the involuntary contractions of the esophagus is not known, but these nerves are probably vaso-motor and secretory, rather than viscero-motor to the esophagus.

Inasmuch as the muscular actions of deglutition require to be performed in sequence rather than simultaneously, it appears that the center, when excited, sends out a series of successive impulses to the various muscles. These impulses may be alternately motor and inhibitory to a given muscular area; in the pharynx, for example, the muscles immediately behind the bolus of food will be contracted while those immediately in front (*or below*) will be relaxed; an instant later when the bolus has passed further the contraction wave will have appeared in muscles just previously relaxed.

Nerve Mechanism of Gastric Digestion.

The digestion of food in the stomach requires the co-operation of two mechanisms; that which regulates the movements of the stomach and that which controls the secretion of the gastric glands. Both actions are purely reflex. Anatomically, the two sets of nerves are inseparable, both centering in Auerbach's and Meissner's plexus.

These plexuses lie, the one between the circular and longitudinal layers of the muscular coat of the stomach and the other between the muscular and submucous coats. In Auerbach's plexus, at least, are found numerous ganglia situated at the intercrossing points of the fibres. Both plexuses are supplied by non-medullated nerve fibres which come through the coeliac plexus from the vagus and great splanchnic nerves.

Like other secretions, that of the stomach increases or diminishes with changes in the blood-supply. Vaso-motor fibres spring chiefly from Meissner's plexus.

The precise distribution of the component elements of the great splanchnic nerve can only be determined experimentally, and by observation of certain pathologic conditions. From these methods it appears that the white rami given off by the spinal nerves from the fifth to the eighth thoracic, inclusive, but especially those from the sixth and seventh thoracic, are distributed to the stomach; those

from the fourth and fifth thoracic to the liver; those from the eighth thoracic to the pancreas; and those from the ninth to the spleen. Distribution to the duodenum and jejunum seems to range from the seventh to tenth thoracic. An experimental or pathological impingement of the eighth thoracic nerve at its emergence from the intervertebral foramen will impair the functional activity of the pancreas in one case or of the small intestine in another, but never affects the liver, whereas a similar impingement of the fourth thoracic produces immediate changes in the functional activity of the liver.

Pyloric and Cardiac Reflexes.

Both the cardiac and pyloric ends of the stomach are usually in a state of tonic contraction which appears to be due to the rhythmic discharge within the muscles of nerve stimuli. During the act of deglutition the cardia relaxes due to the arrival of inhibitory stimuli, and permits the food to enter the stomach; it then closes and its tonus is resumed. The peristaltic movements by which the contents of the stomach are mixed is controlled through the great splanchnic nerve, which seems to carry both inhibitor and augmentor fibres.

When gastric digestion has progressed far enough so that free acid is present in the pyloric end of the stomach, this acid acts as an excitant to afferent nerve-endings and brings about a reflex inhibition of the pyloric contraction; the pylorus opens, and some food is forced by the peristaltic contractions of the stomach into the duodenum. Arriving in the duodenum the acid seems to stimulate another set of afferent nerve terminals which neutralize the effect upon the nerve centers of the former stimulation and the pylorus closes and resumes its state of tonic contraction. This pyloric reflex occurs through a mechanism which has both afferent and efferent fibres in the vagus and splanchnic nerves.

Intestinal Digestion.

Three secretions are essential to digestion in the small intestine, those of the liver, pancreas, and intestinal glands. It is necessary also that the muscular walls of the intestine should execute peristaltic movements which first mix the chyme with the juices and then, in time, move the liquified mass forward on its way.

A special nerve mechanism controls the secretion, storage, and discharge of bile. Both the vagus and great splanchnic nerves

carry efferent fibres to the liver, but the former are the more important as regulators of function. The great splanchnic also, through offshoots of the coeliac plexus, regulates the storage of bile in the gall bladder and its discharge into the duodenum. The discharge is brought about through a reflex mechanism which at the same time relaxes the sphincter muscle surrounding the orifice of the common bile duct and causes contraction of the muscular wall of the gall bladder. The stimulus which excites this reflex is the chemical action upon afferent nerve ends of acid chyme in the duodenum.

The formation and discharge of pancreatic secretion is similarly regulated by a reflex mechanism which has its efferent pathway in the great splanchnic nerve and apparently passes through preganglionic fibres in the eighth thoracic nerve.

The intestinal masculature in the duodenum possesses continuations of Auerbach's and Meissner's plexuses, which receive fibres from the great splanchnic through the coeliac plexus.

Large Intestine.

The muscular wall of the large intestine is innervated, throughout its length, by non-medullated fibres derived from the splanchnics and the lumbar sympathetic, through several subplexuses. Its activities are reflex. A special reflex mechanism provides for expulsion at the end of the intestine of the unusable residue of intestinal contents; the act is called defecation.

Mechanism of Defecation.

This is a reflex mechanism which, unlike most of those involved in digestion, but like to that of deglutition, can be initiated at will and inhibited at will.

Normally the anal sphincters remain in a state of tonic contraction closing the orifice. This tonus is maintained by the action of a nerve center located in the lumbar region of the cord. When faecal matter accumulates in sufficient quantity to exert pressure upon afferent nerve terminals in the rectum, there develops at the same time a sensation of desire to defecate and, if the will permit, the beginning of the complicated act of defecation. If the will forbids the act the sphincter ani muscles remain in tonic contraction and the desire presently lessens or disappears. If, on the other hand, the will permits the natural reflex, the sphincters are inhibited and relax, the rectal muscles contract, the diaphragm flattens to com-

press the abdominal contents, and at the same time the abdominal walls contract. At times the muscles of the thorax are fixed and respiration momentarily suspended in order to aid the contraction of the diaphragm and abdominal muscles.

When the faeces have been expelled and the stimulation of afferent nerves has subsided, the sphincters again contract and all parts return to the previous state.

This function appears to be shared between spinal and sympathetic nerves. The lumbar nerves send branches through the sympathetic chain to the inferior mesenteric ganglion, from which postganglionic nerves pass to both circular and longitudinal muscle layers. The sacral nerves send branches into the hypogastric plexus and thence into the rectal plexus, some of which are preganglionic and end in the hypogastric plexus and some of which pass into the very wall of the rectum.

Relation of Nerves to Absorption.

The processes by which food is absorbed by the intestinal villi and by which nutritive materials are withdrawn from the lymph in the tissue-spaces are only very indirectly under the influence of nerves. The nervous system, it is true, controls both the muscular and glandular activities by which the food is made ready for absorption; it regulates the caliber of the blood-vessels which carry away from the villi the absorbed food; also the nerves preside over the activity of the tissue cells by which they select and utilize nutritive materials. But the actual absorption is not due to specific nerve stimuli but rather is incidental to general nerve activity.

The movement of lymph through the larger lymphatic channels is due more to compression of these channels during muscular action, respiration, etc., and to the action of the valves in preventing backflow, than to other factors. It is probable that a slow, rhythmic contraction of non-striated muscle takes place in the walls of the larger lymph vessels and this is undoubtedly caused by stimuli conveyed by sympathetic nerve fibres. Little is known of this influence.

NERVE MECHANISM OF CIRCULATION

Since the circulation of blood is absolutely essential to the life of any organ or tissue, the blood being the common carrier of both oxygen and nutrition, and the channel through which waste matter is carried away from the tissues, it follows that the physiologic

mechanism by which the circulation is controlled is of extreme importance. The circulatory apparatus, in all its parts, is controlled by the nervous system in such a way as to co-ordinate it not only internally but externally; that is, the parts of the apparatus are made to act in harmony with each other and in proper time sequence, and the different parts and the apparatus as a whole is regulated to accommodate it to the needs of the body. It is highly adaptable to functional needs and environmental changes and this adaptability is entirely brought about through its nerve connections.

From the standpoint of nervous control the circulatory system may be considered under two heads, the **heart** and the **blood-vessels.** Both contribute force used in propulsion and distribution of the blood.

Nerve Mechanism of the Heart.

The immediate nerve supply of the heart muscle is derived from the cardiac plexus and from ganglion cells located in the wall of the heart itself. The cardiac plexus is made up of fibres brought to it by the vagus nerves and from the gangliated cord of the sympathetic by the superior, middle, and inferior cervical cardiac nerves. Some of the fibres which enter the plexus pass through it to terminate directly in relation with the muscle cells of the heart; others are preganglionic to the cardiac nerve cells, from which very short postganglionic fibres complete the pathway.

Myogenic Theory.

Owing to the fact that the mammalian heart may be induced, by chemic or electric stimulation, to continue to beat for some time after being disconnected from its attached nerves, some physiologists have concluded that the heartbeat is **myogenic** in origin; that is, that it results from the effect of the chemical constituents of the blood and lymph interacting with the chemistry of the muscle fibres. This school of thought attributes to the muscle itself the inherent property of contraction, and explains its rhythmicity by postulating special conducting substances, of quasi-muscular construction, which are said to propagate the contraction wave in the proper manner and direction. The auriculo-ventricular muscle-band of His is believed to be such a conductor.

It has never been established, however, that the nerve-cells in the heart itself are excluded as a source of stimuli in such experiments as have been conducted to demonstrate the myogenic origin

of heart action. Embedded as they are in the substance of the muscle, it appears impossible to assure the abolition of their activity. It is known that ganglionic cells elsewhere can continue to respond for a time to stimuli when severed from their central connections. This is probably true of the heart ganglia also.

The responsiveness of the heart to stimuli arising in distant organs, and which could have been conveyed only through the medium of the central nerve system; the changes which occur in heart action in response to pathologic states in other organs; and the obvious influence of emotional states upon heart action, furnish clear evidence that normally, at least, nerves control the heart. It may be left open to question whether this control extends to absolute initiation of every cardiac contraction and to its propagation throughout the heart structure, but even conceding the possibility of limited action originating in the muscle, by far the greater part of the field of heart control remains occupied securely by the neurogenic theory.

Accelerator and Inhibitor Opposition.

The peripheral nerve mechanism which controls the heart is not merely an arrangement of two sets of fibres, the one efferent and the other afferent. The efferent fibres are divided into two sets, one of which carries nerve impulses which, when expressed in the heart muscle, augment and accelerate its contractions; the other being brought to bear upon the ganglion cells in the heart to inhibit, or retard, their activity.

There are thus two mutually antagonistic influences acting upon the heart muscle at all times. The inhibiting fibres traverse the vagus and reach the heart muscle only through the intra-cardiac ganglia; the accelerator fibres traverse the sympathetic and reach the muscle fibres directly. Each of these sets of fibres may be traced back to a central connection.

Accelerator Pathway.

The accelerator fibres arise in a center located in the medulla oblongata beneath the floor of the fourth ventricle. They descend the cord and emerge with the ventral roots of the second and third thoracic nerves. Thence, by white rami communicantes, they ascend in the gangliated cord and these pre-ganglionic fibres terminate in relation with cells in the inferior, middle, and superior cervical ganglia. From these ganglia new (*postganglionic*) neu-

rons arise and descend to, and through, the cardiac plexus as the inferior, middle, and superior cervical cardiac nerves.

Lesions of the cervical cord interrupt this pathway. Interference with the white rami leaving the second and third thoracic nerves likewise increases the heart action by exciting the accelerator nerves or diminishes its action by reducing the conductivity of the accelerators and thereby diminishing the force they are able to oppose to the inhibiting vagi.

Inhibitor Pathway.

The pathway by which inhibition occurs also begins in the medulla, beneath the floor of the fourth ventricle, in a center known as the vagal cardiac center. It is just above the accelerator center and closely related to it. Both right and left halves of the inhibitor center are closely united across the median line, as are the parts of the accelerator center, so that in effect there is one center for control of the heart, the upper part inhibitor and the lower accelerator.

In the vicinity of the recurrent or inferior laryngeal nerves, the vagus gives off preganglionic branches to the cardiac plexus and thence to the intra-cardiac ganglia. Some of these fibres are probably derived from the cranial portion of the accessory nerve, which has joined the trunk of the vagus and the nucleus of which is practically continuous in the medulla with the vagal nucleus.

Afferent fibres from the heart are carried in the vagus. They take origin in the ganglia on the trunk of the nerve, the cells of which give origin to two processes, the one directed peripherally to the heart, and the other directed centrally. The central termination of these afferent neurons is in the cardiac center.

Somewhere in the cerebrum there exists a pathway by which emotional states may affect the activity of either the accelerator or inhibitor portion of the cardiac center. The precise path by which such impulses travel is not known. Some investigators have advanced the theory that an emotional center exists in the optic thalamus, which not only alters the heart action at times but also affects the calibre of blood-vessels throughout the body.

Into the cardiac center pour stimuli from all parts of the body. These affect its activity so as to regulate the heart action to physiologic needs. In the trunk of the vagus are contained fibres which not only inhibit the reflex activity of the cardiac center but also

bring about a general fall of blood-pressure throughout the body by dilatation of blood-vessels; this effect is probably accomplished by the reflection of impulses downward through the cord to the vaso-motor centers; the fibres which produce this effect are collectively known as the **depressor nerve.**

Various theories have been advanced as to the causes of the activity of the cardiac center. It has been held to be due to the chemic interaction between the nerve cells and the surrounding blood and lymph; it has been attributed largely to psychic states, both conscious and subconscious; it has been ascribed to the field of purely reflex phenomena and described as due to the constant reception of afferent impressions not only from the heart but also from other sources.

Of these views the latter is probably the correct one. The activity of the cardiac center is reflex in character. It is not normally under the control of the will at all, though an occasional instance has been observed in which voluntary alteration of the heart rate within wide limits has been observed; these were probably instances of emotional control voluntarily induced.

Inasmuch as the continued action of the heart is absolutely essential to the maintenance of somatic life, it is not surprising that the ultimate nerve control should be located as near the heart itself as possible and indeed **in** the heart to some extent. A partial independence of long central connections is a conservative measure, providing against instant stoppage of the heart in all lesions affecting the vagus or cervical sympathetic nerves. While it is not possible for the heart to continue functioning after sudden destruction of one of the vagi, a ligature may be slowly applied, or a lesion may gradually reduce the conductivity of one vagus nerve to the point where it altogether ceases, and still the heart will continue to act. Division of the ventral roots in the upper thoracic region similarly fails in many cases to completely stop heart action. It is evident that the immediate source of the nerve energy expended in the heart is in the collateral ganglia and that the superimposed nerve mechanisms of the vagi and the sympathetic are regulatory in function.

Nerve Mechanism of the Blood-Vessels.

The blood-vascular system is a highly elastic apparatus; in the walls of arteries and arterioles is a layer of non-striated muscle tissue by the contraction or relaxation of which the calibre of these

vessels can be materially altered, with marked alteration of the amount of compression they exert upon the contained blood stream. The blood pressure of the body is maintained by the contraction of the heart and the action of its valves, by the degree of contraction of the vessel walls, and by lesser factors such as contraction of skeletal muscles, respiration, etc. The two chief factors are heart action and vascular constriction.

Likewise, the amount of blood which enters a given area of the body in any unit of time is determined first by the force with which the heart propels the general blood stream and second by the degree of contraction existing in the walls of the arterioles of that region.

Normally the arteriole walls are kept in a state of moderate constriction known as **vascular tonus**; this tonus may be increased or diminished through the influence of the nervous system, a special nerve mechanism being provided for the purpose.

The nerves which supply the non-striated muscle tissue in the vessel walls are fine non-medullated fibres derived from collateral or peripheral sympathetic ganglia. They are in two sets, stimulation of which produces opposite effects; the one set is **vaso-constrictor** or **augmentor,** while the other is **vaso-inhibitor** or **dilator.** Both are postganglionic.

The ganglia which give origin to the vaso-motor fibres are connected, by preganglionic fibres, with the spinal cord, in the region extending from the upper thoracic segment to the second or third lumbar segment; in addition certain vaso-motor fibres originate in the medulla oblongata and emerge in the trunks of some cranial nerves, and others arise in the sacral segments and emerge with the second and third sacral nerves. Most of the blood-supply of the entire body, however, is regulated from the thoraco-lumbar region of the cord. Preganglionic fibres leave the ventral roots of the spinal nerves by way of the white rami communicantes, pass into the sympathetic and terminate by arborizing in relation with the dendrites of cells in ganglia, near or distant; from these cells the postganglionic fibres arise to pass to the walls of the blood-vessels.

The vaso-constrictor fibres for the head and face arise from the spinal nerves from the first to the fourth thoracic, ascend in the gangliated cord through the stellate, inferior, and middle cervical ganglia, and terminate in the superior cervical ganglion, from which new axons arise to pass by way of the internal carotid nerve

and carotid and cavernous plexuses to the interior of the head. This path controls the blood supply to the cranial nerves, brain, meninges, etc. Other branches of the superior cervical ganglion follow the external blood-vessels of the head and face.

Vaso-motor fibres to the upper extremities arise from the thoracic nerves from the fourth to the tenth, ascend in the gangliated cord to the stellate (*first thoracic*) ganglion, and thence postganglionic fibres are given to the trunks composing the brachial plexus, through which they are distributed to the blood-vessels of the upper extremity.

Vaso-motor fibres for the lower extremities leave the spinal nerves from the eleventh thoracic to the second lumbar, descend to the lumbar and sacral ganglia, and postganglionic fibres leave these ganglia to accompany the lumbar and sacral nerves, with the branches of which they are distributed.

The vaso-motor fibres to thorax and abdomen enter the gangliated cord from the thoracic spinal nerves; those to the thorax are largely distributed through the pulmonary plexuses; those to the abdomen are carried in the trunks of the splanchnic nerves and distributed to ganglia such as the semilunar, aortico-renal, superior mesenteric, and sacral. The great splanchnic nerve in particular, is vastly important from the standpoint of vascular control and regulation of general blood-pressure, because it contains the fibres destined for the abdominal aorta and its great branches which supply the pulpy abdominal viscera. So capable of distension are these arteries and arterioles of the abdominal viscera that, if fully distended, they can contain at once five-sixths of the entire volume of blood normally contained in the body.

Vaso-inhibitor fibres appear to be distributed in much the same fashion as vaso-constrictors, but less definite details are known concerning them. They respond more slowly to stimuli, so that stimulation of a nerve trunk containing both types of fibres will be followed first by constriction and afterward by dilatation of blood-vessels in the innervated area.

The nerve cells in the thoraco-lumbar region of the cord from which vaso-motor fibres arise may be regarded as a series of superimposed segmental centers. They are situated in the ventral column near its base and in the lateral column; the cells are small in comparison with the motor cells. These centers operate reflexly to maintain vascular tonus. It is probable that both the constrictor

and inhibitor centers are constantly sending out opposing impulses but the constrictors normally predominate as is shown by the fact that vessels are usually in a state of very definite contraction. These centers may be influenced by impressions arriving from the periphery and usually are so influenced that they vary their activity in accordance with funtional needs and at all times cause the delivery to each body area of the volume of blood at that moment required.

All the vaso-constrictor centers are brought under a general control for the development of proper co-operation. This control is vested in a general vaso-constrictor center located in the medulla oblongata. An area about one and a half millimeters wide and four to five millimeters long, and ending about four millimeters above the calamus scriptorius, has been experimentally located as containing this center. Section of the medulla above this does not alter the general constriction of vessels, but injury to that area is at once followed by a general dilatation of vessels and fall of blood pressure. The pathway by which this center communicates with the subsidiary centers in the cord is in the lateral funiculus.

No general vaso-dilator enter corresponding to the medullary vaso-constrictor center has been located, and it is probable that none exists.

The vaso-constrictor center usually acts in response to stimuli from the periphery. It may be influenced by psychic states by some unknown pathway. Its excitability is markedly increased by the presence in the blood of an excess of carbon dioxide or by a dearth of oxygen. Toxins of various kinds in circulation in the blood may affect its activity. As will be seen later under discussion of "animal heat," it acts in close co-operation with the perspiratory centers and with the cardiac center.

Summary.

A general reflex vaso-constrictor center in the lower half of the medulla oblongata presides over the contraction of blood-vessels throughout the body. To do this it controls a series of subordinate centers extending from the first thoracic to the second lumbar segment of the cord and lying at the base of the ventral column of gray matter. From these vaso-contrictor and vaso-dilator fibres pass by white rami into the sympathetic, where they spread forward, upward, and downward to supply all blood-vessels. All fibres leaving the spinal nerves for this purpose are preganglionic; they

terminate in sympathetic ganglia from which postganglionic fibres complete the pathway.

NERVE MECHANISM OF RESPIRATION

The function of respiration is controlled by a complex nerve mechanism the action of which is usually reflex, although respiration may be augmented or diminished or temporarily suspended at will. The control of the will is limited; breathing can be suspended by voluntary fixation of thoracic and abdominal muscles to oppose the respiratory movements, but after a short period the stimulation of the reflex respiratory center by the accumulated carbon dioxide in the blood becomes so intense as to overcome the inhibition of the will and the respiratory muscles are given over to the control of the center.

Co-operation of many nerves is required in respiration. For the enlargement of the nasal and laryngeal passages and the cavity of the thorax to admit air freely to the lungs, the facial and laryngeal nerves must co-operate with the intercostal nerves to thoracic walls and with the phrenic nerves to the diaphragm. The facial and the vagus, from which spring the laryngeal nerves, have their nuclei of origin beneath the floor of the fourth ventricle; the intercostals originate in the ventral column throughout the thoracic region of the cord; and the phrenic takes origin from the middle cervical segments of the cord.

From the lungs an afferent pathway is included in the trunk of the vagus.

Inspiratory Center.

The simultaneous discharge of nerve impulses to all the muscles of inspiration, to insure their contraction in a manner proper for co-operation, obviously predicates a general control, a center from which stimuli are at once transmitted to the individual centers for the various muscles. Such a center has been experimentally located in the medulla oblongata at the level of the sensory end nucleus of the vagus nerve. This center is bilateral, as shown by the fact that longitudinal section of the medulla does not interrupt respiratory movements. Destruction of this area on one side abolishes respiratory movements on that side, but permits their continuance on the opposite side.

The stimuli which regulate the activity of this center in accordance with the functional needs of the body seem to be chiefly

chemical—an increase in the carbon dioxide content of the blood and a diminution of its oxygen content. This center perhaps comes nearer than any other in the body to being purely autochthonic. It persists in action after section of many of the afferent nerves which might be expected to convey to it impressions which might serve as a basis for reflex action. Yet the center may undoubtedly be influenced by afferent stimuli coming through many nerves, as well as by volitional impulses descending from the cerebrum. Irritations of the skin, alterations of surface temperature, the irritation of gases in the laryngeal or bronchial passages, have a marked effect upon inspiration.

Expiratory Center.

Co-ordination of the muscles which control the discharge of air from the lungs, chiefly by relaxation of chest walls and diaphragm to permit the elastic recoil of the lungs and by keeping open the upper air passages, suggests that a general expiratory center is in co-operation with the inspiratory center and alternates with it in action. The existence of such a center has only been proven theoretically, but it is believed to lie in close juxtaposition to the inspiratory center; to the two, combined, the name "respiratory center" is usually applied.

Mechanical Excitation.

It is believed that the first inspiration after birth is due to the evaporation from and consequent cooling of the cutaneous surface; many hold, however, that it is due instead to the accumulation of carbon dioxide in the blood and its effect upon the center. In opposition to the chemical theory of excitation, Head has shown that if there be active inflation of the lungs inspiration will be inhibited and expiration augmented. Certainly, in the artificial respiration which is used to resuscitate partially drowned persons, it appears that the mechanical movements which cause alternate distension and collapse of the thoracic walls directly excite respiratory activity of the nerve center.

It is probable that both mechanical stimuli conveyed by afferent nerves and chemical changes in the blood are effective agents in maintaining normal respiration, the former furnishing the physiologic stimuli which excite reflex action and the latter altering the excitability of the center and the intensity of its response.

NERVE MECHANISM OF PHONATION

The nerve mechanism of phonation is closely related, so far as concerns its lower centers and peripheral nerves, to that of respiration. The efferent nerves involved are the superior and inferior (*recurrent*) branches of the vagus. A special center for the control of the phonatory movements has been located in the lower part of the medulla oblongata near the ala cinerea and the upper border of the calamus scriptorius. This center apparently gives off to the respiratory center impulses which cause it to suspend respiratory movements during phonation.

The medullary phonation center is under the control of a center in the cerebral cortex, located in the lower part of the precentral convolution, in close relation to the area for speech memory in the third frontal convolution. The cortico-medullary pathway is probably associated anatomically with the pyramidal tract.

ANIMAL HEAT

The source of the heat which normally maintains the human body at an average mouth temperature of 98.6'F. and at a slightly higher internal and a slightly lower surface temperature, is the chemical action, chiefly oxidation, which takes place in the body. Every muscular contraction, every change in the structure of a tissue cell, liberates some heat. Naturally, most of this heat is produced in the muscles, glands, and viscera where contraction and metabolism are most active. It is fairly evenly distributed throughout the body by the blood, which has a marked capacity for absorbing and distributing heat, and which bathes all the tissues.

To some extent every efferent nerve in the body aids in regulating heat production; each time a nerve stimulus is expressed in an organ so as to induce its characteristic action some heat is released by that resultant action. But there are no special thermic nerves whose sole function it is to excite heat production. None are required. Heat is a common by-product of all chemical change in animal tissue.

The immediate release of heat, however, in any tissue depends somewhat upon the quantity of oxygen present for use in metabolism; it follows that the volume of blood admitted to a given organ in a given unit of time may influence the rapidity with which heat is released in that organ; this is regulated by the vaso-motor nerves which control the calibre and carrying capacity of the blood-vessels.

Thus the vaso-motor nerves may become regulators of heat production to a limited degree.

Heat Expenditure.

If all the heat produced in the human body in the course of even one day were retained within the body, the accumulation would raise the temperature far beyond the point at which life could be maintained. Normally, heat production is nicely balanced by heat expenditure. This expenditure is accomplished through the following channels:

(a) In Warming Food and Drink. A small fraction of the body heat is utilized in raising the temperature of the ingested food and drink to the body temperature. Also, some heat is carried out with the excretion of the waste products of digestion and metabolism; i. e., with the faeces and urine.

(b) In Warming the Inspired Air. Air usually enters at lower than body temperature and absorbs some heat, which is expired with it. This factor of expenditure is, of course, much greater in cold than in warm weather.

(c) In Evaporation of Water from the Lungs. A considerable amount of heat is used up in this way.

(d) In Evaporation of Water from the Skin. About 15% of all the heat produced by the body is lost through evaporation from the cutaneous surface. Free flow of perspiration accelerates this loss, which is therefore greater in warm rooms or warm climates than in cold.

(e) By Radiation and Conduction from the Skin. By far the greater part—69%—of all body heat is expended in this way. Adding the 15% carried off from the skin through evaporation, it will be seen that some 84% to 85% of body heat is expended through the cutaneous surface. Since the rapidity of evaporation depends somewhat upon the amount of perspiration secreted, and this in turn is dependent as well upon the volume of blood furnished the subcutaneous blood-vessels as upon secretory nerve impulses; and since the rapidity of radiation and conduction from the skin likewise depends upon the volume of blood delivered by the arterioles to subcutaneous capillaries, it follows that the chief regulator of heat dissipation is the vaso-motor nerve system.

This point should be emphasized. The immediate supply of blood is the prime factor in determining the rapidity of radiation

and conduction and a factor, though of less importance, is regulating the amount of evaporation. Therefore, the vaso-motor nerves, which control the volume of blood entering any body area at any time, are the important regulators of heat dissipation.

Maintenance of Mean Temperature.

For the maintenance of an even temperature in the body it is essential that at all times the amount of heat used up or expended shall equal the amount produced. A nice balance must be maintained between production and dissipation. Because the production is variable under various circumstances, it becomes necessary that there be some means of varying the expenditure in accordance with physiologic needs. This mechanism of control is the vaso-motor system already described.

The temperature of a given zone or area of the body is immediately controlled by the vaso-motor centers in the cord. A lowering of temperature for any reason is followed by vaso-dilatation and a consequent increase of temperature. Conversely, an increase of heat above normal leads to vaso-constriction and a consequent reduction of heat. These reactions vary at times for numerous reasons, as when the sudden application of extreme cold to a part causes a protective constriction of vessels to prevent a too sudden and too great chilling of the blood. They vary also in pathologic conditions, such as in tissue damage or irritation which requires hyperaemia as a necessary condition for tissue repair, and in abnormal interferences with some part of the nervous mechanism of heat control, which may throw the whole body temperature out of balance. The regulation of temperature is chiefly, though not solely, vested in the vaso-motor nerve system; ordinary regulation takes place through the cord centers; and a general regulation is exercised by the vaso-motor center in the medulla, more or less influenced by the higher center in the optic thalamus. The latter has an effective but not an essential control.

The operation of these nerve centers is largely reflex. It is not to be assumed, however, that special afferent nerves exist whose function is to convey thermal, or calorific, impressions. These impressions travel by all afferent nerves to some extent, but particularly by way of the afferent sympathetic fibres. There is apparently a special conduction pathway in the spinal cord for impressions of temperature, located in the lateral funiculus and chiefly in the spino-thalamic tract.

The centers are undoubtedly influenced to some extent (*as to their excitability*) by the temperature of the blood which bathes them. They do not appear to respond directly to such temperature changes but the vaso-constrictor centers become more or less excitable according as the temperature of the blood is higher or lower.

NERVE MECHANISM OF SECRETION

Secretion is the function of epithelial tissues. The chemical difference in the various secretions is due to histologic differences in the structure of various groups of epithelial cells. The process of secretion is similar in all instances; it consists in the selection from the blood in the capillaries and the lymph in the tissue spaces of certain ingredients which undergo chemical change in the substance of the epithelial cells and from which a new chemical combination is elaborated.

The name "secretion" is applied to this process regardless of whether the substance so elaborated is intended for further use in the body or is selected for discharge (*excretion*) from the body as being no longer useful. Secretion is similarly governed regardless of whether the resultant product is discharged from its gland by way of a duct (*external secretion*) or is taken up from the interior of the gland by the blood-stream (*internal secretion*) and distributed by the blood throughout the body. In all instances the secretory activity of the cell is governed by fine, non-medullated nerve fibres derived from the sympathetic.

The degree to which the sympathetic regulation of secretion is reflex on the one hand or chemical on the other is in doubt. As a rule it appears that every secretion is normally due to a reflex, that is, excited by nerve stimuli sent out in response to afferent stimuli indicating a physiologic need. For example, the secretion of bile and of intestinal juices is plainly due to reflexes the afferent stimuli for which are furnished by the chemical action of acid chyme upon nerve ends in the duodenum. Similar reflexes can be demonstrated for all the digestive secretions.

In the case of the internal secretions, such as that of the islands of Langerhans of the pancreas, which influences carbohydrate metabolism, and that of the suprarenal glands, which influences muscular contractility, the reflex pathways and stimuli are more obscure. In these case, however, it has been clearly demonstrated that the central nervous system exercises a very direct control. It has already been mentioned that puncture of a certain area

in the floor of the fourth ventricle leads to diabetes. Similarly, lesions affecting the tenth thoracic nerve or its white rami communicans, lead to disturbance of the adrenal secretion. The influence of emotional states upon the adrenal secretion is well-known; the quick response of these organs to fear or anger, in the presence of which their secretions are greatly increased and the muscles of the body unusually energized, proves a psychic influence.

The pathway by which the brain influences internal secretions appears to originate in the optic thalamus and to traverse the lateral funiculus of the cord. The secretory centers are located at the base of the ventral horn and in the lateral gray matter of the cord, especially in the thoraco-lumbar region from which the white rami are given off.

Secretory fibres leaving the cord are preganglionic; they terminate either in the gangliated cord or in the collateral ganglia, but always in relation with cells from which postganglionic nonmedullated fibres complete the pathway to the secreting tissue. The afferent limbs of the various reflex pathways which control secretion are usually located in the same general areas as the efferent. That is, to determine the cord segment or segments which control the secretion of an organ it is only necessary to understand the anatomic distribution of the nerves from the cord.

Efferent fibres to the glands are both excito-glandular and inhibito-glandular. These may travel in the same or in different nerve trunks. Excito-glandular fibres are found in the trunks of several cranial nerves (*chorda tympani, glosso-pharyngeal*) and in the second and third sacral nerves, as well as throughout the region from the first thoracic to the second or third lumbar inclusive.

Secretory nerves to the mammary glands leave the spinal cord in the trunks of the third thoracic nerves. Those to the liver in the fourth thoracic, sometimes fifth. Those to the gastric glands leave the thoracic nerves from the fifth to the eighth inclusive, but especially the sixth and seventh. Those to the pancreas leave the eighth thoracic.

The secretion of the thyroid and parathyroid glands is regulated through a pathway in which the preganglionic fibres leave the upper thoracic nerves and the postganglionic arise in the inferior cervical ganglion. In this pathway the preganglionic fibres seem to exert a somewhat less effective influence than is usually the case. The suprarenal glands are controlled through a pathway in which preganglionic fibres leave the tenth thoracic nerve.

The activity of the kidneys is controlled by the last three thoracic nerves by way of the two lower splanchnic nerves and the renal plexus. Ganglia are interposed in this pathway so that the ultimate fibres are all postganglionic and the action of the kidneys entirely involuntary. The dominance of the preganglionic fibres is here very strongly marked. The function of the kidney depends not alone upon the secretory activity of renal epithelium but also upon regulation of the blood-supply. This is accomplished through the lower splanchnics and the renal plexus; a marked polyuria, without sugar content, has been observed to follow puncture of the floor of the fourth ventricle, which fact has led to the conclusion that there exists in close relation to the general vaso-motor center in the medulla a special vaso-motor center for the blood-supply to the kidneys.

Experimental lesions of any of the last three thoracic vertebrae so as to irritate the lower thoracic nerves in the monkey will produce hyperaemia of the kidneys developing presently into a definite nephritis. This nephritis and hyperaemia disappear following complete correction of the lesions.

NERVE MECHANISM OF URINATION

Like that of defecation this mechanism is partly voluntary and partly involuntary. Both the muscles which retain and those which expel the urine are under control of nerves. The sphincter urethrae, by which the bladder orifice is held closed, is in a state of tonic contraction due to the rhythmic arrival of nerve impulses from the third and fourth sacral nerves. The detrusor urinae is excited to contraction by impulses from the middle sacral nerves and also from the upper lumbar nerves. The centers of origin for these two sets of motor nerves are located in the cord in the neighborhood of the fifth lumbar segment.

The act of urination is largely reflex. Afferent impulses, normally developed by fullness of the bladder, pass to the centers governing the sphincter urethrae and detrusor urinae muscles and to the brain. Their effect is to inhibit the tonic contraction of the sphincter and to excite the contraction of the detrusor urinae. If the brain wills to permit urination, volitional impulses descend the cord which have the effect of further inhibiting the sphincter and exciting the detrusor muscle. If the act is to be suppressed, volitional impulses inhibit the detrusor center and excite the sphincter center.

NERVE MECHANISM OF PERSPIRATION

The secretion of perspiration by the glands of the skin requires not only the secretory action of the gland cells but also is regulated by the volume of blood made accessible to these glands. The latter is under control of the vaso-motor nerve system. The former is regulated by a special set of non-medullated nerve fibres derived from the gangliated cord; they arise in cells which receive preganglionic fibres through the white rami from the spinal nerves. These preganglionic fibres leave the spinal nerves from the first thoracic to the second or third lumbar inclusive; they arise in a series of centers situated at the base of the ventral horn. Probably the centers for the head and face are in the cervical cord and their fibres descend to emerge with the upper thoracic nerves and then re-ascend to the cervical sympathetic ganglia; those for the lower extremities are in the upper lumbar segments of the cord. A general perspiratory center apparently exists in the medulla.

While the action of these centers is generally reflex they may be influenced by a variety of conditions: emotional states, changes in the temperature of the body, venosity of the blood, hot drinks, violent muscular exercise, etc., affect these centers. They co-operate closely with the vaso-motor centers.

NERVE MECHANISM OF GENERATION

In the male the testes are innervated by nerves from the spermatic plexus of the sympathetic, which is related to the renal plexus and derives fibres from the tenth and eleventh thoracic nerves, and from the pelvic plexus. The seminal vesicles derive their nerves from the pelvic plexus, as does the prostate gland. The nerves of the penis are derived from the pudendal nerve and pelvic plexus.

The secretion and discharge of the male reproductive fluid is reflex, although psychic states play a strong part in controlling the reflex mechanism for its discharge.

In the female, the ovaries are innervated by the ovarian plexus, homologue of the spermatic in the male, and by the hypogastric plexus. The uterus is innervated by the same plexuses and by the third and fourth sacral nerves. It is probable that the blood-supply of the uterus is controlled by vaso-motor fibres which may be traced back to the lumbar nerves from the second to the fourth inclusive.

PHYSIOLOGY OF THE SPECIAL SENSES

One of the functions of the nerve system is to receive and convey to the brain, for the uses of the mind, or to other nerve centers, to be used as a basis for reflex action, impressions concerning the relations of the body to its environment and of the parts of the body to each other. The nerves which convey these impressions are afferent nerves but do not include all afferent nerves. Those afferent nerves which convey particular impressions, definitely recognizable as belonging to a specific part of the body or arising in a specific kind of stimulus, are known as "Nerves of Special Sense" to distinguish them from "General Sense Nerves", which convey impressions of hunger, thirst, well-being, discomfort, etc. sensations which arise out of the general state of the body as a living organism rather than out of particular acts of the body or special contacts with its environment.

The special sense nerves are usually described as including those which serve the purpose of Touch, Temperature, Taste, Smell, Vision, and Audition. The first two named functions are served by groups of nerves, widely distributed; the remainder each by a pair of nerves, except that the pair conveying taste impressions divide and travel by two divergent pathways (*chorda tympani and glossopharyngeal*) which re-converge at their central nuclei of termination and share the same nucleo-cortical pathway.

Special Sense End-Organs.

Each of the afferent nerves known as a special sense nerve, as it approaches the periphery, becomes related to a specially constructed organ which selects, and transmits to the nerve, only stimuli of a particular character. Some of these end-organs are quite simple, as the tactile corpuscles; others are extremely complex in their organization, as the retina. Each is capable of transmitting one kind, and only one variety, of stimulus to its related nerve-ends. The end-organs thus give to the special sense nerves their particular functions.

Nuclei of Termination.

Each special sense nerve has within the brain-stem nuclei of termination from which new axons arise to continue the pathway to the cerebral cortex. The nuclei of termination act frequently as a point of departure whence the stimuli are partially transferred

by associative tracts to motor nuclei, that they may serve as a basis for reflex action before the stimuli have been translated into conscious sensations in the cerebral cortex, and before volitional activity can be evoked as a consequence of judgment based on the nature of the impressions received.

The terminal nuclei of special sense nerves are also closely related to each other by associative tracts; this is especially true of the nerves of taste and smell.

Areas of Cortical Representation.

The centrally directed tract from the nucleus of termination of each special sense nerve is directed to a particular area of the cerebral cortex, in which the cortical cells receive and interpret the sensory impressions—translate them into conscious sensations.

It has been held by some physiologists that the specificity of function of the special sense nerves is due to the fact that the end-organs select only a certain range of stimuli, which are always interpreted by the brain as vision, audition, etc. because of the range of vibration within which they fall. By others it is believed that the special cortical areas interpret all impressions which reach them as belonging to that range associated with their habitual function. The correct view probably is that there exist in all parts of each special nerve mechanism differentiations which aid in enabling it to deal with one range of impressions to the exclusion of others. Certainly the special end-organs are highly selective, though much less certainly, the nerve fibres themselves may differ slightly in their property of conductivity from other fibres; most assuredly, the cells of each cortical area representative of a special sense are peculiarly constructed to deal with the type of impressions included in that sense. Most important of these is probably the differentiation of the peripheral end-organs.

THE SENSE OF TOUCH

The sense of touch is located by the mind as belonging to the entire cutaneous surface of the body and the mucous lining of the mouth. Innumerable afferent nerve endings in this surface gather and convey to the brain impressions known as tactile. These nerves are quite distinct from those which convey impressions of heat and cold; the surface of the body is therefore supplied with two fairly complete sets of afferent nerves so scattered that no surface area of any extent is without both varieties but that slight intervals are everywhere found between nerve terminals.

Not all the nerve endings of nerves of touch are alike; they differ in different regions of the body and in different animals. In man the principal varieties are:

(a) Free Endings—The pointed or club-shaped processes, the ultimate terminations of afferent nerve fibrils, found in and among the cells of the epidermis.

(b) Tactile Corpuscles—Oval, nucleated bodies found in the deeper layer of the epidermis.

(c) The Corpuscles of Meissner and Wagner—In the papillae of the derma, especially in the palm of the hand and in the fingertips, are situated specialized elliptical bodies of connective tissue surrounding a number of tactile disks to which nerve fibrils are connected. The afferent fibril in this capsule has lost its myelin and neurilemma and is arranged spirally among the tactile disks.

(d) Hair Wreaths—The hair follicles are surrounded, just below the openings of the sebaceous glands, by wreath-like arrangements of uncovered axons, or fibrils, which are a part of the touch apparatus.

(e) Corpuscles of Vater or Pacini—In the palms of the hands, the soles of the feet, the joints, and the external genital organs are special tactile structures of an oval shape, and made up of a capsule of lamellated connective tissue containing a bulb resembling granular protoplasm. The naked axon enters the capsule and comes into relation with the bulb.

Each of these special tactile end-organs is more sensitive than the nerve itself and serves to transmit to the nerve, when impinged upon by outside objects, a sensory impression which, when it reaches the cortex, will be translated into a conscious sensation of touch.

Varieties of Tactile Impressions.

Any contact with an external object is necessarily accompanied by a certain amount of pressure and displacement of the skin. The degree of such displacement determines the intensity of the sensation. This "pressure sense" is quite distinct from the "place sense" by which the brain locates the site of the pressure, although both are carried by the same set of nerves. It has been suggested that the nerve endings in various parts of the body differ slightly in such a way as to impart to each impression a special character which would enable the cortical area of sensation to attribute each impression correctly to its proper location in the body.

This view seems to suppose that the cortical sensory area is a general one into which are poured indiscriminately all the touch impressions from the entire periphery. This is not the case. Each special sensory impression travels by a definite pathway to and through the central nerve system until it reaches a precisely delimited cortical area where it evokes consciousness. The group of cortical cells connected with the touch papillae of the right middle finger, for example, always interprets arriving impressions as arising in that particular finger. The sensory receptive cells have each a limited peripheral communication and cannot become directly aware of stimuli in other regions. However, the associative functions of the cortex are so highly developed that impressions arriving from different cutaneous areas are readily compared and combined at need.

The "place sense" may be described, therefore, as an awareness on the part of cortical sensory cells of the area from which all their information comes.

The pressure sense can be evoked only by stimuli of certain intensity. This intensity varies under different conditions, and to this variable quantity the term "threshold value" has been given. It indicates the degree of pressure required, in any given body area and under given conditions, to arouse awareness of pressure in consciousness.

The sensitiveness of the skin varies greatly in different parts of its surface. The skin of the forehead is very highly sensitive to delicate pressures; that of the heel requires a much greater pressure to evoke a sensation.

Tactile end-organs vary in number in different regions and for this reason tactile discrimination; i. e. the ability to distinguish between the contacts of two points or minute objects in contact with the skin at some distance from each other, also varies. The "touch spots", or spots provided with tactile sense, in the skin of the calf of the leg are only about fifteen per square centimeter, while those in the palm of the hand number forty to fifty per sq. cm. The discriminatory ability of a part of the body seems to be in direct proportion to its mobility; thus the tip of the tongue possesses the closest discrimination; that in the upper extremities increases downward from shoulders to fingers.

Weight Sense.

The stereognostic, or "weight" sense, is in reality a combination of the pressure sense with impressions arising in tendons and muscle ends and apprising the sensorium of the amount and character of muscular effort involved in the act which evokes the weight sense. It is brought into play by lifting or grasping objects. The tactile sense is seldom used alone. Almost always some deliberate effort is involved at the same time and the measure of this effort, together with the amount of pressure developed against the skin, is utilized by the brain in forming a concept of weight or density.

THE TEMPERATURE SENSE

The ability to distinguish heat and cold, as compared with the normal body temperature, is due to the existence of a special mechanism, or rather two mechanisms, one for heat and one for cold. Scattered among the tactile end-organs in the skin are a number of special end-organs, insensitive to touch, some of which register heat and transform it into a nerve wave, while others register only cold and similarly translate that into a nerve wave.

The pathways by which these temperature impressions traverse the medulla spinalis have been located in the ventrolateral column of white matter and in the gray matter. They ascend to the optic thalamus, which probably contains a thermic center for the regulation of body temperature in accordance with the afferent stimuli received. This thalamic center is undoubtedly connected with the cerebral cortex, in which consciousness of temperature is developed, but with exactly what areas we do not know.

The physiologic stimulus to the activity of the thermal end-organs is the passage of heat from the interior to the surrounding air. Naturally, the sensitiveness to temperature changes depends upon the thickness of the skin, the heat conductivity of the object touching it, and the degree to which it has been habitually exposed. The sensitiveness to heat is, on the whole, strongly marked; most of the body can readily detect a change of one-half degree centigrade.

PAIN SENSE

The sensation of pain is not evoked by a particular variety of nerve waves arising through the action of special end-organs upon stimuli of a certain range of vibration, but is due rather to an intensification of ordinary stimuli beyond the normal, or to damage

done to nerve ends which renders them abnormally sensitive to stimuli which could ordinarily be borne.

Thus light, the normal stimulus for the optic mechanism, may evoke pain in disease of some part of the optic apparatus. Sounds, normally borne by the auditory mechanism, may become painful either by great increase in their intensity or by a pathological increase in the sensitiveness of the conveying mechanism. The same is true of all varieties of afferent impressions arising from the outside world.

Pain arising from conditions of the internal viscera, poorly endowed with sensory nerves and these derived from the sympathetic rather than from the cerebrospinal system, has to be transferred from the sympathetic system to the cerebrospinal before it can register in consciousness. This mechanism of transfer has been described: it consists in the cells of Dogiel in the spinal and cranial nerve ganglia, to which afferent visceral impressions of sufficient intensity will irradiate, and which in turn will give these impressions to cerebrospinal afferent neurons in the same zone. When these impressions reach the cortex they arrive by a pathway ordinarily employed for the conveyance of impressions arising in a cutaneous area, and are interpreted by the brain as coming from the body surface. Thus, pain arising in the vermiform appendix as a result of inflammation is felt as if it belonged to the surface of the abdomen somewhere in the vicinity of the appendix. Because of the fact that both visceral and somatic nerves from a given segment are distributed in the same body area, there is much diagnostic value in the location of pain due to visceral disease.

THE MUSCLE SENSE

Closely related to the tactile sense is that sensation arising in impressions generated in the special afferent end-organs in tendons and in the ends of muscles by the contraction of muscles. The muscular contractions, by compressing the end-organs, generate nerve waves which pass to the central nerve system, reach the cortex, and are there interpreted as information concerning the posture of the body and the degree of muscular effort exerted by its parts.

It should be remembered, in discussing these various special sensations, that a great part of the afferent stimulus generated at the periphery does not reach the consciousness at all but is expended, along the course of the nerve pathways, in evoking reflex action or unconscious muscular co-ordination. This is especially true of

the muscular or tendinous sense, much of which acts upon motor centers in the spinal cord and still more upon the cerebellum, without evoking consciousness. Only the residue, as it were, of this group of impressions, ordinarily reaches consciousness, although by an effort of will the mind may become aware of them to an unusual degree.

The central pathway by which the muscle sense is conveyed is found chiefly in the posterior funiculus of the cord. A part traverses the inferior peduncle to the cerebellum; the remainder follows the medial lemniscus to the thalamus and thence to the cortex in the parietal lobe, particularly the super and sub-parietal convolutions.

THE SENSE OF TASTE

The sense of taste, or **gustatory sense,** is evoked by the action upon special end-organs of chemical stimuli of a non-destructive nature.

The mechanism includes the taste buds on the surface of the tongue and adjacent mucous membranes of the mouth, the chorda tympani and glossopharyngeal nerves, their cortical connections, and nerve-cells in the fourth temporal convolution.

The tongue presents three varieties of papillae containing taste-buds:

(a) The **filliform papillae,** over the anterior two-thirds of the tongue, are conical or filliform in shape, and covered by epithelium which is prolonged into filamentous tufts.

(b) The **fungiform papillae,** chiefly on the tips and sides of the tongue, less numerous than the preceding, are deep red in color.

(c) The **circumvallate papillae,** are eight to ten in number and are situated at the base of the tongue in a V-shaped arrangement. Each consists of a central prominence surrounded by a wall.

Taste-Buds.

In physiologic relations with the peripheral terminals of the nerves of taste are numerous special organs called taste-buds. They are found not only on the tongue but also on the palate and the posterior surface of the epiglottis. Each bud is ovoid in shape. Its base rests on the tunica propria; its apex erects itself to the epithelium where it presents a narrow, funnel-shaped opening, the **taste pore.** The interior of the bud contains neuro-epithelial

cells, fusiform in shape, and provided at their outer extremities with hair-like filaments which project into the taste-pores.

The terminal branches of the gustatory nerves enter the taste-bud at its base and split into tufts which come into intimate physiologic relation with the neuro-epithelial cells, which are, indeed, probably modified nerve ends.

Taste Sensations.

Four primary taste sensations can be recognized. These are: bitter, sweet, acid (*sour*) and salt (*saline*). There is a difference in the sensitiveness of various parts of the tongue to these separate sensations, though all can be detected throughout the taste area if sufficiently intense. Thus the posterior part of the tongue is more sensitive to bitter substances than the anterior while the reverse is true for sweets.

THE SENSE OF SMELL

The olfactory mechanism consists of the pituitary (*Schneiderian*) membrane in the nose, the olfactory nerves, olfactory tracts, and the olfactory area of the cerebral cortex, in the uncinate convolution and gyrus fornicatus.

The olfactory cells are bipolar nerve-cells embedded in the nasal mucosa. The peripherally directed process of each cell is cylindrical or conical in shape and at its extremity splits up into several hair-like projections; these rise above the level of the mucous membrane where they can be impinged upon by the vibrations of particles of volatile matter contained in the air current within the nose.

These particles of matter must be drawn through the nostrils in an air current of some velocity, in order to be appreciated. If they are widely diffused through the atmosphere, it is often necessary to take air in forcibly in order to detect the odor. The "sniff" of a dog is an instinctive act for the purpose of enabling the animal to detect an otherwise obscure odor.

Taste and Smell.

Many sensations commonly classified as taste by the individual are, in reality, smell. If the nostrils be closed so that air is temporarily prevented from passing through, a substance placed on the tongue may seem "tasteless" whereas, with the removal of the nasal obstruction, a very definite sensation is at once developed. Through

experience the mental associations between taste and smell have become intricately blended.

Range of Olfactory Development.

The mammalia, as distinguished from fishes and amphibians, have a relatively great olfactory development. Most land animals use the sense of smell not only as a means of discovering and judging food but also for the detection of their enemies. In humans, this mammalian development of smell has receded as the dominance of psychic faculties has increased. It may be said that the olfactory apparatus in man has developed in inverse ratio to the evolution of the neopallium. It occupies a very small part of the brain in man and a very large part in some animals, as in hunting dogs.

Classification of Odors.

Only by experience can an odor be mentally assigned to its proper cause. That is to say, an odor having been repeatedly experienced, the individual associates its presence with certain substances found in the place from which it emanates. He perceives these substances by bringing into play the other senses; sight, hearing, and touch. Repeated association between a substance and its odor finally enables the brain, through the use of stored-up memories, to identify an odor without the visible or palpable presence of its cause.

Odors in general have an effect upon the mind which is either agreeable or disagreeable. That is they arouse either liking or repugnance. The standard of agreeability varies so much in different races of men and in different individuals that it cannot be attributed to any actual influence upon the tissues of the body but must be ascribed rather to acquired ideas as to the nature of the substance causing the odor. The odor of frying onions is undeniably agreeable to some persons; to one who has been made ill by eating fried onions it may well be very unpleasant.

Keenness of Smell.

Sensitiveness to odor varies greatly in different persons, and in the same person under different conditions. Any pathologic change in the nasal mucosa may diminish or abolish the sense of smell, as will obstruction which hinders the passage of air through the nasal chambers.

In general it may be said that exceedingly minute quantities of certain substances give off a perceptible odor; and that the olfactory sense may be trained. Concentration upon the detection of precise odors will enable the mind to appreciate and identify faint olfactory impressions which, in ordinary individuals, would never reach the threshold of consciousness.

PHYSIOLOGY OF VISION

The function of vision is served by an exceedingly complex apparatus, specially constructed so as to receive but one type of stimuli—ethereal vibrations within a certain range—transform them into nerve impressions, and transmit them to the cerebral cortex where they are recognized as light, color, or the form of objects.

These completed visual perceptions may at once become the basis for motor actions of various kinds, or they may be stored up as sense memories to be utilized in future cerebrations.

Many of the impressions gathered by the optic mechanism are utilized otherwise than in the perfection of vision, being diverted from their course to the cortex as stimuli for nerve centers which control motor activities. Evidence of this is found in the fact that in certain brain lesions which destroy vision the pupillary reflex, a response to the introduction of light into the eye, may be demonstrated.

Special Stimulus.

The retina, the nervous tunic of the eye, contains the ganglionic cells of origin which give rise to the axons of the optic nerve and in addition a series of highly specialized layers which gather and transmit to the ganglionic cells impressions derived from the impingement upon them of ethereal vibrations ranging between about 450 trillions per second on the one hand and 880 trillions per second on the other. Vibration rates above and below these limits are not registered. The selectivity of the optic mechanism for this particular group of stimuli lies in the structure of the retina rather than in the makeup of the optic nerve axons.

The retinal layer which is directly acted upon by light vibrations is the layer of rods and cones.

Rods and Cones.

These are the percipient elements of the retina; the cones have been estimated as numbering about 3,500,000 and the rods about

100,000,000. In the macula lutea the cones alone are present, being about 4 micromillimeters apart, and from the fact that in the fovea the retinal image is formed and vision most exact, it is concluded that the cones are the most essential element of precise vision. The rods, however, perceive light and its component elements, color.

The Retinal Image.

One of the chief functions of the eye is the implantation upon the retina of images of external objects. The light striking an object is either reflected or absorbed by it and if the eye be directed toward that object the resultant rays which enter the eye are so concentrated upon the central part of the retina, the macula lutea, as to create there an image of the object which differs from the object in size and in the fact that the image is inverted and reversed, like the camera image.

The image is due to a rearrangement of the structure of the peripheral ends of the rods and cones, more especially the latter, in response to the action of light. It is generally conceded that chemical change takes place in the rods and cones under the photochemical action of light rays.

The layer of rods and cones is in connection with the bipolar cells of the retina and these in turn with the ganglionic layer. The change which takes place in the percipient layer with the formation of the image thereon is transmitted to the ganglionic layer in such a way as to excite the cells to send centralward nerve impressions, the character and intensity of which are determined by the shape of the image and intensity of the rays which form it.

Experience enables the cortical cells of the visual area of the brain to invert and reverse the image when it is received, and to identify it with an object, or class of objects, previously made familiar by association of vision with touch, audition, and other senses.

The Eyeball.

In order that visual images may be properly formed upon the macula lutea the amount of light entering the eye must be regulated and the rays must be properly converged. The structure of the eyeball is adapted to these purposes.

The eyeball is nearly spherical in shape and between its anterior surface and the retina are interposed a number of transparent

media through which light rays are freely admitted. The iris alone is a non-transparent structure surrounding an aperture, the pupil; by its contraction or dilatation the iris regulates the amount of light entering the eye and accommodates the eye to changes in the intensity of light and to its alterations between near and distant vision.

The cornea, crystalline lens, and aqueous and vitreous humors are media which refract the rays of light so as to converge and cross them at a proper point in the eyeball so that an image of the proper size will be projected on the retina.

The eyeball is supplied with extrinsic muscles which move it in such ways as will bring it to bear upon desired objects of vision and so regulate the position of the two eyes in relation to each other that images will be formed on homologous areas of the two retinae and superimposed in the brain to form a single image. Failure of the ocular muscles to bring about entirely co-ordinate action of the eyes results in the formation of two separate images in the mind instead of one—double vision, or diplopia.

Nerve Control of the Iris.

The iris is made up of two sets of muscle fibres, circular and radial. The circular fibres, or sphincter pupillae muscle, are innervated by the oculomotor nerve and contraction of the sphincter pupillae with consequent narrowing of the pupil and reduction in the amount of light permitted to enter the eye is a reflex phenomenon. The afferent limb of the reflex arc is by way of the retina and optic nerve to the superior colliculus. From the colliculus the impressions are transferred to the special portion of the oculomotor nucleus which innervates the sphincter pupillae, and excites this center to action.

The dilatator pupillae, made up of radial muscular fibres of the iris, is innervated by the sympathetic from the ciliary, or ophthalmic ganglion. This pathway may be traced back through the cavernous plexus and internal carotid nerve to the superior cervical ganglion and this ganglion is found to receive preganglionic connections from the upper two thoracic spinal nerves. A center for pupillary dilatation has been located in the medulla. This dilatator mechanism seems to be in a state of tonic activity, tending at all times to maintain the pupil in a state of enlargement except as the varying impulses which pass by the oculomotor pathway temporarily dominate. There has been much discussion as to whether

the action of the dilatator mechanism is automatic or reflex; it is probably reflex.

Adaptation of Refracting Media.

When the eyes are fixed upon an object 65 meters distant, the light rays entering the eyes are practically parallel. To converge these rays properly, the cornea and crystalline lens remain somewhat flattened. Rays from nearer objects may approach the eye divergently and require a greater degree of refraction, wherefore the cornea and lens, but particularly the latter, become more convex.

Modifications of the convexity of the lens are brought about by the action of the ciliary muscle, which is controlled by the oculomotor nerve through the ciliary ganglion. The changes in the shape of the lens are reflex.

Like many other reflex phenomena these can be instituted by an act of volition. That is to say, a conscious effort to change from distant vision to near vision, while it does not directly command the intrinsic muscles of the eyeball, acts as a release upon the reflex mechanism which accomplishes the necessary changes in the iris and the lens.

Movements of the Eyeball.

Of the extrinsic muscles which rotate the eyeball in various directions so as to increase the field of direct and clear vision, the superior oblique is innervated by the trochlear nerve, the external rectus by the abducens nerve, and the remaining muscles, the internal rectus, superior rectus, inferior rectus, and inferior oblique, are supplied by the oculomotor nerve.

The nuclei of these three nerves are in intimate central connection and all communicate freely with the lower visual centers, especially the superior colliculus, so that a part of the visual impressions carried by the optic nerve and optic tract are diverted to the control of the eye movements. These movements, like so many others, may be initiated voluntarily or may be reflex in origin. Likewise the motor centers for ocular movements are connected across the median line with those of the opposite side so that coordination of the movements of the two eyes may be assured.

For fixing the eyes upon a near object the eyes turn inward by contraction of the two internal recti, so that the visual axes cross

at the object and diverge as they enter the eyes. This allows the two images to form on homolgous spots in the two retinae and permits of the superimposition of the images when they reach the cortex. The internal recti, both innervated by the oculomotor nerve, require for their conjoint activity the stimulation of two centers, a right and a left. It appears that either of these centers can influence both internal recti at once, and this is probably accomplished by means of association fibres which enable one center to divide its stimulus with the other.

When looking to one side, that is to the right or to the left, a different conjugation of muscles is required. To look to the right for example, the eyeballs must turn in that direction simultaneously. This involves contraction of the right external rectus innervated by the sixth nerve, and the left internal rectus, controlled by the third. The precise pathways of communication within the brain-stem by which this association of nerve centers is arranged are not positively settled but it appears clear that there is an intimate communication between nuclei.

Associated Movements.

Visual reflexes, that is, reflex movements resulting from visual impressions, are by no means confined to the extrinsic and intrinsic muscles of the eyes. The muscles of the neck which rotate the head and those which flex and extend the neck, are very frequently brought into play to support the movements of the eyeballs in their effort to secure distinct vision.

The lower visual centers, the pulvinar of the optic thalamus, the lateral geniculate body, and the superior colliculus, possess extensive connections with other motor cranial nerve nuclei than the ocular, and with spinal motor centers as well. A considerable portion of the impressions gathered by the optic nerve are diverted at these lower centers of vision, so that they never reach the cortex for translation into consciousness. Much time is saved in this way, since the interval required for a reflex response to a stimulus is definitely less than that required for the development of consciousness and volition. Protective movements of the head, for example, when a menacing object approaches the eye, are much quicker than they could be if mental recognition of the menace and a decision to avoid it were necessary before action could take place.

At times almost all the skeletal muscles may respond to a visual impression diffused through the motor centers—as a blinding flash of light.

The Conducting Pathways.

The light rays which pass through the almost spherical eyeball cross each other in so doing; those which enter the temporal side of the cornea are thrown upon the nasal side of the retina and vice versa; those entering the upper part of the eyeball are projected upon the lower half of the retina: it is this crossing of rays which accounts for the fact that the retinal image is an inverted and reversed picture of the object seen. This is corrected in the cortex.

The "field of vision" is the somewhat cone-shaped space comprehended within the range of vision of the eyes in any given position. It shifts, of course, with movements of the eyeballs and of the head or body. It is narrowest near the eyes and expands as the distance increases up to the limit of visual perception. In reality the field of vision is made up of two fields, one for each eye, which fuse medially.

All light rays entering from the right half of the visual field reach the left halves of the two retinae; those from the left half of the visual field reach the right halves. In ordinary vision an object seen to the beholder's right side is perceived by both retinae, the nasal half of the right and the temporal half of the left.

The optic nerve is a gathering of fibres derived from the ganglionic layer of the retina and conveying visual impressions. It is formed at the back of the eyeball, a little medial to the posterior pole and a little below its level. At its junction with the retina is formed a slightly raised spot, the optic disk, in the middle of which is a small area containing no rods or cones and therefore a blind spot; this is caused by the presence of the arteria centralis retinae which here leaves the trunk of the optic nerve to enter the retina and divide into branches.

The optic nerve is said to carry in its interior a special group of fibres corresponding to the macula lutea.

Each optic nerve represents the entire path of visual conveyance from one retina. The nerve enters the cranial cavity by the optic foramen and above the sella turcica of the sphenoid joins its fellow of the opposite side at the **optic chiasma.** Here a rearrangement of fibres occurs. Those fibres from the nasal side of the retina cross the median line to continue backward to the lower visual centers in company with those from the temporal side of the opposite retina, under the name of the **optic tract.** The crossed fibres occupy the center of the chiasma and the uncrossed its periphery

or lateral margins. The crossed fibres are the more numerous. Various estimates have been arrived at by different investigators but that view which holds that about two-thirds of the fibres of each optic nerve decussate at the chiasma is probably nearest correct.

Each optic tract therefore, represents not one eye but one half of the field of vision. All impressions derived from the right half of the visual field are conveyed to the brain by the left half of the optic tract and all from the left half of the visual field by the right optic tract. Lesions interrupting one optic tract and not the other will consequently produce blindness as to the objects of one side of a median plane, projected forward from between the eyes, while a lesion interrupting one optic nerve produces blindness of one eye.

The fibres of the optic tract terminate in the pulvinar of the optic thalamus, the lateral geniculate body, and the superior colliculus. In those lower visual centers there occurs a distribution of the impressions transmitted by the retina. Some are diverted, especially through the new neurons arising in the superior colliculus, to the motor centers for the nerves of the eye, and to other motor cranial and spinal nerve centers; these serve as the basis for many and complicated reflex actions. The remainder are taken up by new neurons arising in the pulvinar and lateral geniculate body and conveyed by the optic radiations toward the occipital cortex.

An area in the neighborhood of the calcarine fissure is devoted to the reception and interpretation of visual impressions and the storage of visual memories. It associates by long arcuate fibres with other cortical areas and is connected with the lower visual centers by efferent fibres which do not continue to the eye.

The optic nerve differs embryologically from other nerves in that the retina, from which the optic nerve fibres grow, is formed from the cells of the optic disk at the end of the optic stalk which is projected forward as a diverticulum from the forebrain substance. The ganglionic layer of the retina may be regarded as a detached portion of the brain and likened to the bulbo-medullary gray matter. Within the retina are short neurons which actually constitute the peripheral nerves of vision; and they are connected with the layer of rods and cones, which constitute the special perceptive end-organs suited to the visual apparatus.

An interesting fact about this arrangement is that the rods and cones are an inner layer and the light rays, to reach them, must pass successively through the other retinal layers as well as

through the refracting media of the eye. These layers are transparent and offer no obstacle to the passage of the light, except at certain limited areas where arteries lie. Under normal conditions of vision the visual images are formed without impinging upon these areas but under certain abnormal conditions imperfect images are formed with shadow marks because of them.

Complete and detailed discussion of vision and visual defects is beyond the scope and volume of the present work. As a special field of study this subject is almost exhaustless. Fortunately, there are innumerable books of reference dealing with every phase of optics and particularizing in detail, where this work must of necessity merely sketch the outlines of the subject.

PHYSIOLOGY OF AUDITION

The eighth cranial nerve is functionally two nerves rather than one; the one division, the acoustic nerve, is the special sense nerve of hearing; the other, the vestibular division, is the nerve of equilibrium and the nerve which conveys space sense.

Both these nerves are developed from the ectodermal layer and each is the result of a gradual and special modification of the tactile apparatus. That is to say, hearing is in reality a highly developed variety of touch. The stimulus which arouses it is the vibration of the particles of the air which have been set in oscillatory motion. These vibrations of the atmosphere are imparted to the acoustic nerve ends by means of a special apparatus in such a manner that they excite nerve waves varying according to the variations in the intensity and rate of the stimulus. These nerve-waves, or impressions, are interpreted in the brain as sound and its qualities, intensity, pitch, and timbre.

The Auditory Mechanism.

The mechanism for the reception and interpretation of sound is made up of the external ear, consisting of the **pinna** or **auricle** and the **external auditory canal;** the **middle ear** or **tympanum,** containing three articulated ossicles, the malleus, incus, and stapes; and the **internal ear,** containing the labyrinth and the organ of Corti, in which are the acoustic nerve ends; the acoustic nerve, the terminal nuclei in the ponto-bulbar region; nucleo-cortical pathways; and a cortical area in the temporal lobe. A passageway between the tympanic cavity and the naso-pharynx, known as the

Eustachian tube, may also be regarded as a part of the auditory mechanism since it serves an essential function by allowing the equalization of air pressure on the two sides of the tympanic membrane.

The Stimulus.

An atmospheric wave, aroused by an expression of force or a movement of matter in the environment, and traveling in an undulant fashion by the oscillation of air particles, is gathered by the external ear and strikes the tympanic membrane which is thereby thrown into vibration of a similar rate and intensity to the air vibration. The tympanic vibration is then transmitted through the chain of ossicles to the labyrinth of the internal ear, and through the fluid of the labyrinth to the organ of Corti.

There are divergent views as to the precise manner in which the displacement of liquid and the liquid currents in the labyrinth excite the acoustic nerve ends. Helmholtz held the organ of Corti to be comparable to the strings of a piano, each attuned to vibrate in a certain key when stimulated and each selective of a certain range of vibration only. Other views compare the acoustic nerve ends to tactile nerve ends and hold that all are susceptible, within their limits, to whatever vibrations reach them, and faithfully transmit these to the brain. This view gives to the cortical cells in the auditory area the sole power of discriminating and of recognizing sound by the rate, intensity, pitch and timbre. The latter view is probably the correct one.

The range of vibrations perceptible as sound is from a possible minimum vibration rate of about 14 per second up to a possible 70,000 per second. Tones encompassed in the realm of music range from about 4,000 to 40,000 vibrations per second. Sound waves traverse the air at a rate of about 1,090 feet a second at sea level and in moderate temperatures.

Function of External Ear.

The external ear, by means of its trumpet shape, directs the sound waves against the tympanic membrane at precisely the right angle. In some of the lower animals which possess mobile ears the position of the external ear makes a great difference in the acuteness of auditory perception. In man this is not the case but hearing may be aided by tipping the pinna forward or by cupping a hand behind it so as to increase the collecting surface.

Function of Tympanum.

The tympanic membrane transmits vibrations to the ossicles, of which one, the malleus, is in direct contact with the membrane. The tension of the tympanic membrane is alterable by means of contraction of the tensor tympani muscle, which tightens the membrane and enables it to transmit higher vibration rates, or relaxes and thus loosens the membrane for the transmission of lower vibration rates. The tensor tympani works reflexly, the afferent nerve being carried by the fifth nerve from the tympanum and the efferent nerve being derived from the motor division of the fifth.

In order that the membrane may function properly a balance must be maintained between the external and internal air pressures exerted upon it. This is accomplished by way of the Eustachian tube. Forceful air pressure on the outside of the membrane causes it to bulge inward and increase the pressure in the middle ear. Some air then escapes by way of the Eustachian tube. When the tympanic membrane returns to its normal position the air pressure within the cavity would become rarefied were it not that the Eustachian tube again admits air to balance it. If for any reason the tube is occluded and fails to perform its pressure-regulating function, hearing is impaired; sound become muffled and confused. This often occurs in catarrhal inflammations of the naso-pharynx extending into the Eustachian tube; the result is known as "catarrhal deafness."

Action of Ossicles.

The **malleus** is attached to the tympanic membrane and gives attachment in turn to the tensor tympani muscle. Its head articulates with the concave articular surface of the **incus.** The **stapes,** or stirrup-bone, articulates externally with the long process of the incus and internally, by its oval base, with the edges of an oval opening, through which it communicates its vibrations to the perilymph of the internal ear.

The Internal Ear.

The internal ear is subdivided into the **vestibule, the semicircular canals,** and the **cochlea.** The vestibule receives in its fluid the vibrations from the middle ear and divides them between the semicircular canals and the cochlea; the former are organs of equilibrium connected with the vestibular nerve and the latter is the organ of hearing, connected with the cochlear, or acoustic, nerve.

The **Cochlea** has the form of a cone twisted spirally upon its own axis. It is channeled out of the interior of the petrous portion of the temporal bone and inside the bony walls contains a smaller membranous duplicate of those walls, filled with endolymph.

Within the membranous cochlea is contained the organ of Corti. It extends the entire length of the cochlea and is made up of a number of rods standing side by side and ending in hair-like receptive processes.

The Cochlear Nerve terminates within the cochlea in branches which reach the organ of Corti; its origin is in the cells of the spiral ganglion in the internal ear. The centrally directed processes of these bipolar ganglion cells enter the internal auditory canal as the cochlear nerve in intimate association with the vestibular nerve, so that the two together are commonly described as the eighth cranial nerve. Between the two divisions in the canal lies the pars intermedia, or nerve of Wrisberg, unrelated to the acoustic nerve but belonging rather to the facial. The acoustic nerve enters the brain-stem in the dorsal portion of the post-pontine groove and the cochlear fibres then diverge from the vestibular.

The connections of the cochlear nerves have been described. (page 46). From the nuclei of termination the pathway for audition continues centralward by the lateral lemniscus. Cell stations exist in the inferior colliculi which probably have to do chiefly with auditory reflexes. The medial geniculate body is an interposed cell station between the lemniscus and the temporal cortex.

The cortical center for audition is in the spheno-temporal lobe, especially the superior temporal convolution. This is in rather close relation to the motor centers for speech and the speech memory centers. Each ear is connected with both cerebral hemispheres.

Variations in Sound.

The **intensity** or loudness of a sound depends upon the amplitude of the vibration which caused it. The greater the swing of the vibrating body the greater the energy by which it strikes the ear.

The **pitch** of a sound depends upon the number of vibrations per second which strike the ear. The greater the number the higher the pitch. A very low rate of vibration causes no appreciable sound. On the other hand, vibration may attain so high a rate as to pass beyond the perceptive range of the auditory mechanism. It is said

that some of the lower animals are capable of perceiving vibration rates beyond the reach of human ear and that this is especially true of some insects.

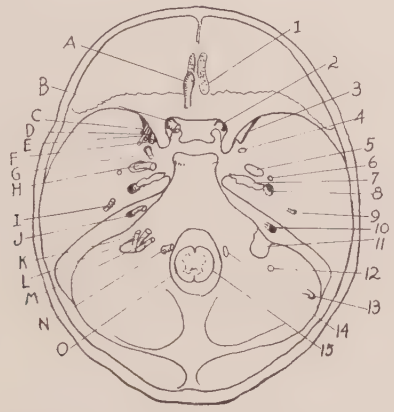

Fig. 101. Plan of Floor of Cranial Cavity—Exits of Cranial Nerves.
1, Cribriform Plate of Ethmoid; 2, Optic Foramen; 3, Superior Orbital Fissure; 4, Foramen Rotundum; 5, Foramen Ovale; 6, Foramen Spinosum; 7, Foramen Lacerum; 8, Carotid Canal; 9, Canalis Facialis; 10, Internal Auditory Meatus; 11, Jugular Foramen; 12, Condylar Foramen; 13, Mastoid Foramen; 14, Hypoglossal Canal; 15, Foramen Magnum. A, Olfactory; B, Optic; C, Oculomotor; D, Trochlear; E, Ophthalmic; F, Abducent; G, Maxillary; H, Mandibular; I, Facial; J, Acoustic; K, Glossopharyngeal; L, Vagus; M, Accessory; N, Hypoglossal; O, Bulbo-Spinal Junction.

The **quality** of a sound depends upon the **form** of the vibration. The form of a sound wave is the resultant of a combination of a fundamental vibration and certain secondary vibrations of subdivisions of the vibrating body. The union of fundamental and secondary vibrations gives rise to a composite sensation which is recognized as the characteristic tone of a certain musical instrument or voice.

THE SENSE OF SPACE AND EQUILIBRIUM

Not all of the internal ear is devoted to the function of audition. A special mechanism which receives a portion of the atmospheric waves known as sonorous is devoted to the exteriorization and localization in space of these waves. Partly as a consequence of this localization of sound and partly by another function of the same mechanism, the relation of the body to the plane of the earth's surface is determined and the function of **equilibrium** is served.

The Mechanism.

The **semicircular canals** are connected with the vestibule as is the cochlea. Like the latter, the canals are both osseous and mem-

branous, the latter contained within the former and separated from it by fluid. The membranous canals are partially filled with fluid and the upper level of this fluid changes its relation to the canal walls with changes in the attitude of the head.

Vibration waves entering the vestibule agitate the fluid of the semicircular canals as well as the cochlea, and the nerve ends of the vestibular nerve in the walls of the semicircular canals are excited by this agitation and convey to the brain impressions which are so interpreted as to develop a sense of the direction from which the vibrations have come. This sense of space is so closely linked with audition that it is not usually appreciated separately. We hear a sound as coming from a certain direction or location; actually, two sets of nerve fibres have entered into the conveyance and the impression is composite instead of simple.

Equilibrium.

The terminals of the vestibular nerve in the semicircular canals are minute hair-like projections from the surface. These are easily excited by changes in the relation to the walls of the fluid which partly fills the canals. Since the three canals are placed each approximately at right angles to the other two and since all communicate freely with each other, every change in the position of the head in relation to the earth plane is registered upon the vestibular nerve-ends and results in the conveyance of nerve waves centralward.

The vestibular nerve directs its long processes centralward in company with the cochlear nerve and enters the brain-stem in the post-pontine groove. It connects with the vestibulospinal tract and with several nuclei from which new axons arise to pass to the cerebellum. Probably some fibres of the nerve itself reach the cerebellum before terminating.

The cerebellum is a co-ordinating center for those muscular activities of a synergic nature by which the balance of the body is maintained during the performance of complicated acts like standing, walking, and running. It may be considered as a highly developed reflex center for the execution of complex reflex activities which may or may not be initiated by the will. It receives afferent impressions from all parts of the body which serve as a basis for its activities. Perhaps the most important single avenue of information for the cerebellum is the apparatus including the semicircular canals.

Damage to the canals by inflammatory processes, as in Meniere's disease, is characterized by marked vertigo and loss of equilibrium, and also by a certain degree of deafness, due as much to the loss of space sense as to any other factor.

Visual and Tactile Space Sense.

The auditory apparatus is not the only one which localizes impressions but it is the only one in which the localizing mechanism is separate from the sense-perceptive mechanism. The retina not only perceives visual impressions but assigns them to a location in space. The sense of touch includes appreciation of the location of objects in contact with the skin. Even the temperature sense registers the direction from which heat waves are arriving by the inequality of their action upon different body areas.

It is by means of this localization in space by different senses that the images derived from different senses become superimpossible in the brain. That is the connecting link which enables the mind to identify sight, sound, and touch impressions as coming from the same object because all originate at one point or locality in space. Repeated experience and successive identifications of the various sense impressions as related to an object enable us to pass from mere sensation to an idea and the vocal or graphic sign representing it, then from the simple to the general idea, from the concrete to the abstract.

SYMPTOMS AND DIAGNOSIS OF NERVE LESIONS

INTRODUCTION

All nerve disorders may be roughly divided into two groups, **organic** and **functional.** The line of demarcation between these groups is by no means distinct; disturbances of function may arise from morbid changes in nerve tissue so obscure as to elude detection even at autopsy; on the other hand a functional disease, continuing, may in the course of time develop a discoverable pathology. It is probably true, in fact, that no departure of neurons from normal functional activity ever occurs without accompanying changes—either as cause or effect—in the nerve tissue itself; there are many nervous aberrations, however, which can never be associated with any definite lesion, and these are classified as functional, while those in which a demonstrable morbific change has taken place are known as organic.

The diagnosis of organic nerve disorders, or nerve lesions, has two major objectives; the determination of the **type** of the lesion (*pathological diagnosis*) and the ascertaining of its **location** (*regional diagnosis*). The former is important as leading to a possible foreknowledge of the probable development and duration of the process, its danger to life, etc.; the latter is particularly valuable because it indicates the procedure necessary for correction if correction is possible. Surgical procedure for the removal of a nerve lesion demands exact location of that lesion; manipulative measures for the removal of interferences by other tissues with nerve integrity require a precise localization of the effects of such interference. It is impossible to exaggerate the importance of precise locative diagnosis in the examination of the nervous system.

We shall present the following order of subdivisions:

1. Organic Diseases.
   - A. Regional Diagnosis.
   - B. Pathological Diagnosis.
2. Functional Diseases.
   - A. Functional Disorders Confined to Nerve System.
   - B. Functional Nerve Disorders with Extra-Neural Effects.

REGIONAL DIAGNOSIS OF NERVE LESIONS

Certain preliminary consideration are necessary to a proper approach to the practical study of nerve lesions.

Relation of Symptoms to Location of Lesion.

The function of all nerve tissue is to receive, to generate, or to transmit nerve stimuli. Any lesion, of whatever pathologic character, may interrupt or disturb this function and most of the symptoms arising from the lesion will be symptoms of interruption of the passage of nerve energy through accustomed channels. Recognition of these symptoms depends upon a complete knowledge of nervous anatomy and physiology. That is, through exact knowledge of the physiologic effects of the stimuli normally travelling through any given group of neurons or passing any given point in the nervous system, the practitioner should be able to reason backward from the group of symptoms presenting itself in a case to the location of the interrupting lesion. For example, if sensory functions alone are abolished or modified, it is easy to conclude that the pathologic process is to be found entirely in the sensory portion of the nerve system. The area or extent of sensory involvement will usually serve to locate the lesion in a single nerve root, in the spinal cord, or in the brain. If a single type of sensation is involved, it is logical to seek for the interference in some part of the nerve system where this function is dissociated in its conducting pathways from other types of sensation. While it is rarely possible by means of any single symptom or fact to relate an abnormality to the exact location of its cause, it is usually possible, by studying in turn **all** of the abnormal effects, to so narrow the field of possibilities as to make the regional diagnosis quite certain. The **combination** of symptoms makes the diagnosis and there is a slightly different combination for every change in the area of involvement of the nerve system.

In no other tissue is there such regular correspondence between the location of disease and the nature and distribution of symptoms. Neurological diagnosis should therefore be of all the most exact, but unfortunately, owing to the general lack of detailed knowledge concerning nerve functions, this is not the case.

Upper and Lower Neuron Systems.

As has already been shown, the somatic efferent neurons are divided into two groups, the **upper** and the **lower.** The term "upper

neurons" is applied to all neurons of an efferent character above the set of neurons which makes the final link in the motor pathway to the periphery; to this last group of neurons which connects the spinal cord and its prolongation into the brain with the muscles the term "lower neurons" is applied. It must be understood that while a single neuron may arise in the cerebral cortex and descend to the ventral horn of the cord to make a direct connection with the lower (*peripheral*) neuron and the two complete a direct motor pathway, in many instances not a single upper neuron but two, three, or even five or six, placed end to end and communicating with each other by means of synaptic connections, may be required to establish the pathway from cortex to ventral horn. All these neurons above the lowermost are called equally "upper neurons".

The lower neurons are spoken of as arising in the spinal cord, but in fact the nuclei of origin of all the motor cranial nerves are likewise the beginnings of lower motor neurons and are reached and influenced by upper motor neurons in precisely the same way that spinal nerve nuclei are influenced. The axis of gray matter from which the peripheral motor nerves are projected extends the entire length of the spinal cord and through the interior of medulla, pons, and mid-brain into the base of the cerebrum. This entire axis is the origin of the lower motor neurons.

The upper motor neurons originate in the cortex of the cerebrum and their axons descend in fibre tracts of white matter which in the spinal cord lie external to the gray matter and, with other white tracts, serve to envelop it. A transverse section of the cord at any level would therefore interrupt both upper and lower neuron systems; a lesion in the ventral horn of the cord might interrupt only the lower neuron functions; and a lesion in the internal capsule, in the brain, being entirely above and detached from the nuclei of origin of the peripheral neurons, would interrupt only the upper neuron functions.

Functions of Upper and Lower Motor Neurons.

A brief review is here in order.

The upper motor (*cortico-spinal*) neurons, located in the ventral and lateral cerebrospinal fasciculi, convey to the cranial and spinal nerve nuclei impulses to voluntary muscular action and also exert over them an inhibiting influence which governs the reflex excitability of the lower neuron cells.

Every nerve-cell is trophic to its processes; i. e., governs the ability of the processes to take up and utilize nutritive material throughout their extent. Interruption of the continuity of any neuron therefore causes degeneration of the portion detached from connection with the cell body while the attached portion continues able to maintain its nutrition.

In the indirect motor pathway each of the several linked neurons which descend from cortex to cord presides over its own nutrition and transmits motor stimuli, usually of an involuntary character, to the ventral horn cells. Whether the indirect motor path exerts an inhibiting influence upon reflex activity is not clearly known but apparently it does not, since in lesions affecting the direct but not the indirect motor pathway the reflexes are commonly exaggerated.

The lower neurons have their cell bodies in the gray matter of the spinal cord, medulla, pons, mid-brain, and the base of the cerebrum. Their processes project outward as the motor or efferent components of spinal and cranial nerves. They make the final connecting link with the voluntary muscles.

The cell body of the lower neuron, like the upper, governs the nutrition of its processes. Thus, even though a lower neuron be entirely deprived of the regulatory influence of the upper neurons it will continue to be properly nourished and to maintain its conductivity unless its own cell bodies be injured or destroyed. A characteristic of lower neuron lesions is atrophy of the peripheral nerve fibres, while in upper neuron lesions the peripheral nerves do not atrophy.

The function of the lower neuron cells is to transmit through their axons the impulses to voluntary motion received from the upper neurons and at the same time to respond by reflex activity to impressions arriving from the periphery through afferent nerves. Also the lower neuron cells may respond to stimuli derived in roundabout way from the cerebrum by the indirect motor pathway, routed by way of the cerebellum, and bringing about involuntary muscular action of complicated and co-ordinated character.

The lower neurons may be interrupted by lesions of the gray matter of the cord or the central gray matter of medulla, pons, mid-brain, or base of cerebrum, the effects being limited to the nerve fibres arising in the particular area of gray matter affected

and the remaining lower neurons continuing to function. Or lesions of the peripheral nerve trunks may abolish the activity of the lower motor neurons belonging to that nerve as well as the lower sensory neurons.

Upper and Lower Sensory Neurons.

It will be remembered that the peripheral afferent or sensory neurons arise in cell bodies situated outside the brain-stem and in the ganglia attached to the cranial and spinal nerves. From the cell bodies processes travel in two direction; the longer process peripheralward to make a connection with some variety of sensory end-organ, and the other process (*short or long*) entering the spinal cord or brain as the case may be, to proceed centralward. This ascending process terminates somewhere within the cord or brain in relation with a cell group or nucleous of termination from which new axons arise to continue the path toward the cortex. Usually more than one neuron is interposed between the central end of the lower, or peripheral, sensory neuron, and the ultimate destination of the sensory impressions traversing that pathway. A single group of sensory neurons, those nearest the periphery, is classified as "lower sensory neurons", while several groups may be superposed above as "upper sensory neurons".

Section of the lower sensory neuron **below** the ganglion of origin leads to atrophic degeneration of the peripheral portion thus severed from its cell body, while the centrally directed process remains undegenerated because it retains its connection with the source of its nutritive activity. Cutting of the lower sensory neuron **above** the cell of origin causes it to degenerate **upward**, that is within the central axis, but leaves the peripheral portion without atrophy. Either interruption will, of course, abolish sensation so far as that particular neuron is concerned and equally of course, will abolish any reflex acts which depend upon the reception of the special afferent stimuli carried by that neuron.

Within the cord the sensory neurons undergo a distribution quite different from that which they occupy in the peripheral nerve. In the nerve trunks, each nerve carries all the sensory nerve fibres from a limited body area; thus all types of general sensation and one or more types of special sensation may be carried by a single peripheral nerve, which at the same time conveys outward voluntary and involuntary motor impulses and impulses which have arisen reflexly. At the intervertebral foramen, in the case of the spinal

nerves, a separation takes place between the motor and sensory elements of the nerve so that a lesion between the separation and the cord might affect only one side of the nerve cycle.

Within the cord the afferent radicular fibres are divided into long and short bundles. Some of the longer fibres ascend in the fasciculi gracilis and cuneatus to terminate in nuclei in the medulla. The lower neuron may thus extend a great distance; those of the sciatic nerve may reach from the foot all the way to the medulla. The shorter root fibres terminate in the gray matter of the cord at various levels. Some of them turn downward, as those in the comma tract, and enter the gray matter. Others cross the cord (*mostly collaterals*) and end in the gray matter of the opposite side at the level of their entrance or slightly higher. Still others enter Clark's column of the same side; these latter convey impressions which will be carried to the cerebellum by way of the spino-cerebellar fasciculi.

In the sensory pathway, the neurons arising in the nucleus gracilis and the nucleus cuneatus, the spino-cerebellar, spino-thalamic and spino-tectal fasciculi, the nucleo-cortical, striato-cortical, and other ascending neurons of the cerebrum all belong to the "upper sensor neuron" class as distinguished from the single group of neurons classed as "lower" and distributed to the entire periphery. The posterior funiculus of the cord (*fasciculi gracilis and cuneatus*) contain lower neuron fibres while the ascending tracts of the lateral funiculus are of the upper neuron variety.

Sympathetic Neurons.

The sympathetic neurons have their cell-bodies in the ganglia of the great sympathetic trunk, or in the ganglia of the prevertebral plexuses, or in collateral ganglia. Whether the axons of these cells are distributed directly to the viscera and internal blood-vessels, or join spinal and cranial nerves as gray rami communicantes to be distributed in company with the somatic nerves, their own cell-bodies control their nutrition and the neurons as a whole possess a certain limited measure of independent function. Certain reflex arcs traverse the afferent and related efferent sympathetic nerves without passing through the central nerve system. The reflex excitability of the ganglia is to some degree presided over by the cranial or spinal fibres which reach them, but is not entirely dependent upon such control.

It follows that while lesions of the peripheral sympathetic neuron will completely interrupt its conductivity and abolish its function, lesions of the central nerve system involving the preganglionic fibres may have a partial but incomplete arresting effect upon the sympathetic activity, or may cause it to become inco-ordinate and unbalanced. Because of this partial dissociation of function between cerebrospinal and sympathetic systems extensive cerebral or spinal lesions may permit the vegetative functions to continue with little impairment.

EXAMINATION OF THE NERVOUS SYSTEM

Leaving out of consideration for the time being all psychic manifestations and many symptoms of so-called "functional disorders", the practitioner who desires to examine the nervous system for the detection of organic abnormalities must first consider that the common function of all nerve tissue is the generation and conduction of nerve stimuli; that lesions in the nerve system manifest themselves by interruption of normal nerve function; and that all such interruptions fall naturally into two groups, **Motor Disturbances** and **Sensory Disturbances.**

MOTOR DISTURBANCES

The expression of motor stimuli in the form of muscular contraction may be exaggerated or diminished. An exaggeration, however, if persistent, is more likely to be due to the removal of a governing or checking influence than to increased excitation. For example, the exaggerated reflexes and increased muscle tonus which accompany hemiplegia of the central or cerebral type are due rather to abolition of the inhibiting influence normally exerted by cerebrospinal neurons upon the ventral horn nuclei in the cord than to any irritation in the lower neurons. Diminution or abolition of motility, on the other hand, indicates either a destructive lesion which has diminished or abolished the conductivity of some certain neurons, or dystrophic changes in the muscles themselves. The effects of all nerve lesions are largely **negative,** seldom **positive.**

Increased Motility.

Spasm. Abnormally intense muscular contractions are termed **spasms.** When spasms become general and involve all, or nearly all, the skeletal muscles, they are known as **convulsions.** Spasm is due to excessive activity of the lower motor neurons, which in turn depends either upon heightened excitability of the motor gray matter of the spinal cord, so that it responds too strongly to normal afferent or voluntary stimuli, or to lessened inhibition from the cerebrum. In the former case the cause is usually found in the action of certain toxic drugs, such as strychnine, or in the action of a specific toxin of bacterial origin as in tetanus. In the latter case, a lesion somewhere in the upper neuron system has interrupted the governing influence usually exerted upon the ventral

horn cells and without this check they produce an exaggerated response to those afferent stimuli which serve as a basis for reflex action.

Increased muscle tonus and exaggerated reflexes usually occur together and are due to the same causes, for muscle tonus is a reflex phenomenon though usually described separately from the other reflexes which require to be especially elicited.

Spasm may be **tonic**—lasting a long time without intermission—or **clonic**—a series of brief contractions separated by intervals of relaxation.

Tremor. A slight exaggeration of muscle tonus, insufficient to maintain the muscle in a state of spasticity, produces a continuous quivering or trembling of the extremities known as **tremor.** Muscle tonus is normally maintained by a series of nerve stimuli, reflexly aroused, and traversing the peripheral motor neurons at the rate of 10 or 12 per second. If each of these impulses is slightly augmented the resultant quivering will be invisible but sensible to touch; it is called **fine** tremor. If the augmentation is sufficient so that the muscle cannot sufficiently relax following one contraction so as to be ready for the next, and the alternate contractions are therefore largely unexpressed, the resultant 5 or 6 vibrations per minute are perceptible to the eye and are called **coarse** tremor.

Test for Tremor. To ascertain whether tremor is present, direct the patient to extend his arm, and observe the trembling of both hand and arm. Fine tremor, which cannot be seen, may be felt by placing the tips of the examiner's fingers against those of the patient.

Tremor which is present when the patient is attempting no voluntary movements is **passive** tremor; that which develops only upon attempt to execute intentional movements is **active** tremor.

Tremor of the facial muscles is best elicited by asking the patient to close the eyes tightly or to raise the upper lip or to protrude the tongue.

Diagnosis of Tremor. Tremor is associated with both functional and organic disease. It may proceed from extreme weakness or inanition. Intention tremor usually signifies organic disease while passive tremor commonly proceeds from functional conditions. Tremor of the facial muscles, lips, and tongue, is usually significant of marked alcoholism, neurasthenia, or paresis.

There are certain special conditions or diseases with which tremor is associated.

In persons of nervous temperament under excitement or alarm tremor is normal. Temporary tremor may occur even in healthy persons after violent or long-continued exertion. Senile tremor (*fine*) which begins in the hands and finally spreads to the neck so as to cause the head to tremble, is common in old people but rarely appears before the age of seventy.

The tremor of paralysis agitans is a coarse tremor affecting especially the extremities and sometimes the head. The movements of the thumb and forefinger are somewhat characteristic, often taking the form known as "bread-crumbling". This tremor disappears during sleep and sometimes is absent during voluntary movements.

Exopthalmic goitre is accompanied by a fine tremor, rarely visible. The fine tremor of hysteria usually affects the hands and arms, less often the head and hands.

In disseminated sclerosis a coarse or slow volitional tremor is especially marked.

Tremors result often from the persistent overuse of tea, coffee, alcohol, and tobacco, and from lead, mercury, arsenic, or opium poisoning. Alcoholic tremor affects especially the tongue and hands and often shows itself only upon movement.

Fibrillary Tremor. This is a tremulous twitching limited to certain fibres or bundles of a muscle. It indicates wasting of a muscle from lack of neurotrophic influences, as in progressive muscular atrophy, or profound exhaustion of a muscle.

Athetosis. This may be a separate disease due to congenital or acquired abnormalities in the optic thalamus, or may be associated with cerebral paralysis. It consists of a series of apparently purposeful but actually involuntary, slow, twisting movements. especially of the upper extremities, exaggerated by efforts at voluntary motion. The movements are slower than those of chorea. Repeated pronation and supination of the hands and alternate flexion and extention of the hands and feet occur. Speech is sometimes rendered difficult by athetoid movements of the facial muscles.

Jacksonian Epilepsy. This is a localized convulsive seizure which begins with tingling or numbness in an extremity, proceeds

to violent contractions of a muscle or group of muscles, and then develops so as to involve the entire extremity. It is not attended by unconsciousness except in the rare cases where the convulsion becomes general. It is usually caused by a localized irritation of the sensorimotor area of the cerebral cortex which may be due to brain tumor, softening, localized meningitis, hemorrhage, abscess, or injury.

Febrile Tremors. In very serious fevers, especially in the gastro-intestinal diseases of children and in the typhoid status, may occur irregular moderate twitchings of muscles, especially those of the face, arms, and hands. They indicate great weakness and may occur also in delirium tremens, jaundice, uraemia, or meningitis, or as a result of the use of certain drugs. **Carphologia,** picking at the bedclothes and attempting to seize invisible objects out of the air, is seen in the typhoid status and may be a sign of impending death; at the least it indicates a very grave weakness.

Choreic Movements. These are abrupt twitching or jerking movements of muscle groups, usually shifting from group to group, and entirely involuntary. If on one side only the term **hemichorea** is applied. The movements usually cease during sleep, are increased by excitement or fatigue, and diminished by voluntary movement. To detect slight choreic movements it may be necessary to lay the hands of the examiner upon those of the patient; extreme choreic movements may be so violent as to require that the patient be forcibly restrained lest the movements hurl him from the bed.

The commonest cause of choreic movements is Sydenham's chorea, the acute chorea of children. Among other conditions which have choreic movements for a symptom are Huntington's (*chronic*) chorea; convulsive tic; saltatory spasm; habit spasm; and rhythmic chorea, which is really hysteria; the latter includes "nodding spasm" when the neck muscles are involved, and "salaam convulsions" when the abdominal muscles are the seat of the contractions. In this class also may be named paramyoclonus multiplex, which is characterized by either continuous or intermittent contractions, of considerable violence, occuring chiefly in the extremities.

Cramp. A cramp is a localized, painful muscular spasm. It is most common in the calf muscles. Its immediate cause may be gout, alcoholism, diabetes, nephritis, hysteria, or muscular exertion.

Contractures. If a tonic muscular spasm be continued long enough it develops alterations in the structure of the muscle, espe-

cially of its fibrous stroma, whereby the muscle is shortened and becomes incapable of extension to its full normal reach. This condition may be unnoticed except when effort is made to execute passive movements of the part connected to this muscle when, at the limit of the muscular extensibility, an abrupt check is felt, similar to that which occurs from pulling a lax, but attached, rope taut. In some instances contractures may be so strong as to seriously limit movement, in others, slight.

Contractures arise from a variety of conditions. Organic disease such as hemiplegia may produce them as a permanent effect of the spasticity which accompanies this type of paralysis. They may be due to hysteria, in which case they are likely to disappear during sleep. Permanent contracture of the sternocleidomastoid may set in in cases of torticollis. Contractures often occur in the unparalyzed muscles opposite to a flaccid paralysis. They may be due to local nerve irritations.

Tetany. This is a condition in which the flexors of the hands and feet and sometimes the muscles of the jaw (*trismus*) are the seat of paroxysmal tonic spasms. The hand assumes a peculiar attitude known as "the accoucheur's hand."

Paralysis.

Definitions:

Paralysis is a partial or complete loss of voluntary motor power.

Palsy is often used as a synonym for paralysis; more commonly, to indicate paralysis agitans (*Parkinson's disease*).

Paresis is a term applied to a partial loss of motor power. Also applied to general paresis of the insane.

Amyosthenia is a sudden temporary weakness of arms or legs, occurring in hysteria.

Hemiplegia is paralysis of one lateral half of the body.

Crossed or **alternating hemiplegia** is that in which the extremities of one side and the facial, ocular, or other muscles of the opposite side are paralyzed.

Diplegia is a double hemiplegia, both sides paralyzed.

Quadruplegia is a paralysis of the four extremities not involving facial or ocular muscles.

Paraplegia means paralysis of both lower extremities except where the term "brachial" is prefixed, or the term "paraplegia superior" is used to indicate loss of power of both upper extremities as distinguished from "paraplegia inferior."

Monoplegia is paralysis of a single member; as, brachial—the arm, crural—the leg, facial—the face. Double brachial monoplegia may be described.

Examination for Paralysis.

The survey must consider each of the following points:

1. The location or extent of the paralysis. Does it involve one muscle, a group of muscles, an entire limb, both lower limbs, or one-half the entire body?

2. Is the paralysis of the spastic or flaccid type? Test by passive movements; if these are resisted and the muscles firm to the touch they are **spastic.** If they offer no resistance to passive movement and are limp and inert under the touch they are **flaccid.**

3. What is the nutritive condition of the muscles? Are they markedly atrophied? Or are they normal or only slightly atrophied from disuse?

4. Are the reflexes exaggerated, diminished, or normal?

5. Are there sensory disturbances, and if so what is their extent and which sensations are involved?

Upper and Lower Neuron Types of Paralysis.

Most cases of paralysis may readily be assigned to one of two types: (a) Upper neuron, central, cerebral, or spastic paralysis, and (b) Lower neuron, peripheral, flaccid, atrophic, or spinal type.

Upper Neuron Type.

It must be remembered that the upper neurons not only make up a large part of the cerebrum but also descend the spinal cord in its ventral and lateral columns to terminate at successive levels by entering the gray matter. The upper neuron type of paralysis may therefore be due to a lesion in the brain or to a lesion at any level of the cord affecting the ventrolateral white matter. It is spoken of as being of cerebral type even though located in the cord. It is also called "spastic type" because it is invariably accompanied by spasticity due to the removal of the inhibiting influence of the upper neurons from the lower and the consequent exaggerated response of the latter to peripheral stimuli.

Clinical features of this type are its **distribution**—hemiplegia, partial or complete; **spasticity; exaggerated reflexes;** the slight **atrophy,** if any; and the usual **absence** of **sensor involvement.**

Direct causes of the central type of paralysis are any lesions which involve the cell-bodies or axons of the upper neurons. Thus the lesion may be **cortical,** affecting the cells of origin; it may be in the internal capsule, basis pedunculi, pons, medulla, or ventro-lateral region of the cord.

Pathologically, it may be due to hemorrhage, embolism, or thrombosis, to cerebral softening, to unilateral lesions of the cord such as hemorrhage, tumor, etc. In cord lesions the hemiplegia is not complete but exists only below the level of the lesion. Since the causes of the cerebral type of paralysis are usually unilateral, the distribution is commonly that of hemiplegia, the paralysis being on the side opposite to the lesion because of the crossed conduction of motor impulses.

There is little in the distribution of cerebral paralysis or in the condition of the muscles to indicate the precise pathological **nature** of the causative lesion. The manner of onset, whether gradual or abrupt, and associated symptoms other than paralytic, may suggest the pathology. A history of syphilis, for example, may suggest the luetic nature of a brain lesion. History of high blood-pressure or arteriosclerosis, followed by a sudden apoplectic hemiplegia, suggests cerebral hemorrhage. Often the exact pathology cannot be determined ante-mortem, but this is of less importance from the standpoint of treatment than recognition of the type of paralysis and exact location of the lesion.

Lower Neuron Type.

The lesion may affect the cell-bodies in the gray matter of the cord, or any portion of the peripheral nerve fibres arising therefrom. It must be remembered that the nuclei of origin of the motor cranial nerves, extending in a series downward from the base of the cerebrum through mid-brain, pons, and medulla, are homologous with the spinal motor nerves, and that lesions affecting these nuclei, as well as the spinal, will produce lower neuron paralysis.

This paralysis is flaccid because the lower neurons are completely interrupted and the muscles cut off from the reflex stimuli which maintain muscle tonus. There is a distinct difference be-

tween a merely relaxed muscle and a toneless muscle, a difference easily distinguished by the experienced examiner.

The reflexes are partly or wholly abolished in lower neuron paralysis.

The muscles undergo marked **atrophy** owing to the shutting off of the neurotrophic influence. If electrical tests are made it will be found that the **reaction of degeneration** is present, indicating nerve atrophy.

Sensory Involvement.

If the lesion be in the motor cell bodies in the cord there is no direct sensory involvement. Paresthesias may develop from impaired circulation but these are readily distinguished from diminished or abolished sensation. If the peripheral nerve trunk is affected, as in peripheral neuritis, both the motor and sensory fibres will lose their function and anesthesia will be distributed over the paralyzed area. The presence or absence of anesthesia is the determining factor which decides whether a lower neuron paralysis belongs to the gray core of the central axis or to the peripheral nerves.

The term "peripheral" is applied to all cases of the lower neuron type. All are flaccid and atrophic.

The Dystrophies.

This type of paralysis sometimes appears to begin in the muscles with marked atrophy and sometimes pseudohypertrophy before the reaction of degeneration demonstrates nerve atrophy. The motor nerve and muscle constitute a neurotrophic unit, and there seems insufficient ground for classifying these muscular atrophies, obviously due to loss of the neurotrophic influence, separately from the lower neuron type of paralysis. They should be considered as muscular atrophy of spinal origin. Treatment must in all such cases be directed to arresting the process in the ventral gray matter and to rebuilding such cells as are not yet destroyed, and this regardless of whether the first symptoms appear in muscles or nerves.

Diagnosis of Paralysis According to Type.

The cerebral type of paralysis indicates a lesion of the motor cortex or pyramidal tracts, usually unilateral (*hemiplegia*), less commonly bilateral (*diplegia in children*), or a lesion affecting the crossed (*lateral*) cerebrospinal tract in the cord.

The spinal type of paralysis is due to lesions affecting the gray matter of the cord or its continuation upward in the interior of the brain, or the peripheral nerves. This includes the so-called "muscular dystrophies."

Functional paralyses are usually due to hysteria. They are flaccid in type but do not exhibit the reaction of degeneration or atrophy. The deep reflexes are variable but rarely abolished as in other flaccid paralyses. Functional paralyses are usually transient and may shift from place to place, thus conclusively proving that they are not due to organic lesions.

There exists a mixed type of paralysis, partaking of the characters of both the upper and lower neuron types and due, in fact, to simultaneous involvement of both. The lower neuron cells are affected by the same process which attacks the terminals of the upper neuron fibres. This is seen in amyotrophic lateral sclerosis, in which rapid muscular atrophy is combined with spasticity and exaggerated reflexes. In the latter stage of this disease the upper neuron symptoms are obliterated by the complete loss of function in the lower neurons and the last stage resembles the permanent stage of poliomyelitis—a syndrome of flaccid paralysis, marked atrophy, abolished reflexes.

Conclusions from Distribution of Paralysis.

Hemiplegia (*complete*) is nearly always due to a cerebral lesion; if incomplete, that is not involving head or neck, it is more commonly due to unilateral lesion affecting the lateral column of the cord. Double hemiplegia is due to transverse lesions affecting the cord except in the diplegia of children.

Complete hemiplegia of the usual type (*face of one side and arm and leg of the same side*) is due to a lesion of the knee and the anterior two-thirds of the posterior limb of the internal capsule. Here the entire motor pathway is compacted so that a limited lesion will affect all of it and here cerebral hemorrhage occurs oftenest because of its proximity to the lenticulo-striate branches of the middle cerebral artery; these are the most direct terminal arteries of the brain and the most liable to arteriosclerosis and to feel the effect of sudden increases in blood-pressure.

If the lesion of the capsule invades the adjacent optic thalamus, convulsions or athetoid movements may be added to the paralytic symptom complex.

When only the posterior limb of the internal capsule is involved, the genu escaping, the picture is that of hemiplegia of the body with the head and face unaffected. To this is often added hemianesthesia when the lesion extends into the area of transit of the great sensory tract, which lies occipitalward from the motor tract.

Right hemiplegia with aphasia in a right-handed person, suggests that in addition to the internal capsule, the third left frontal convolution is affected.

Hemiplegia with crossed oculo-motor paralysis is due to a lesion in the cerebral peduncle which not only involves the descending pyramidal tract but also affects the oculomotor nerve on its way through the peduncle after leaving its nucleus. In this case, while the general hemiplegia is of the upper neuron type, the oculomotor paralysis is lower neuron type.

Similarly, a lesion in the pons may affect the cerebrospinal tract which crosses lower down to the opposite side, and also involve the facial nerve after it has left its nucleus and is following its tortuous course toward its superficial origin. This facial paralysis is of the lower neuron, flaccid, atrophic type.

Hemiplegia with anarthria (*difficult speech*) and difficult swallowing, is caused by lesions in the medulla.

Knowledge of the exact anatomy of the motor cranial nerves and study of the manner of their involvement in any case of hemiplegia should enable the examiner to locate the brain lesion with great accuracy.

An acute and sudden hemiplegia is usually due to cerebral hemorrhage. Embolism and thrombosis may develop abruptly or more slowly. These vascular conditions usually ensue upon arteriosclerosis, though cerebral syphilis may be a factor. Less common causes of hemiplegia are brain tumor, multiple sclerosis, meningeal hemorrhage or abscess, and general paresis of the insane. It may occur in hysteria, or, transiently, in uraemia.

Paraplegia.

Paralysis of both legs may be due to spinal cord lesions or to multiple neuritis. Spastic paraplegias are usually due to limited, transverse, spinal lesions, cutting off the pyramidal tracts but leaving the reflex arcs intact below the level of the lesion. A flaccid paraplegia may be due to disease of the anterior horns of the cord

extending vertically throughout the lumbo-sacral region. If caused by peripheral nerve lesions (*bilateral*) the flaccid paralysis will be accompanied by anesthesia since in this case the sensory as well as the motor elements of the peripheral nerves will be involved.

The diseases in which paraplegia of the spastic type occurs are: lateral sclerosis; spinal meningitis, pressure from Pott's disease, hereditary ataxic paraplegia, multiple cerebro-spinal sclerosis, chronic myelitis, transverse myelitis (*spastic below level of lesion*), syphilis of the cord, and that spastic cerebral palsy of children in which only the legs are affected.

The flaccid type of paraplegia may be due to: Landry's paralysis, Friedrich's ataxia, hemorrhage into the cord or the spinal meninges, acute poliomyelitis, tumor or tuberculosis of the cord, neuritis, hysteria, and diphtheria. There is a senile paraplegia due to arteriosclerosis, thrombosis, or embolism of the spinal arteries. Among the most frequent causes of paraplegia are acute poliomyelitis and alcoholic neuritis.

The differential diagnosis of all cases of cerebral and spinal paralysis must be made from associated symptoms. The type and distribution of the paralysis clearly indicates the location of the lesion but tells nothing about the pathology, since any lesion produces its paralysis merely by destroying the functional power of some set of neurons.

Monoplegia.

Brachial monoplegia is usually due to a limited cortical lesion or to peripheral neuritis but, if the shoulder also is involved and there are no sensory disturbances, it may be due to a limited lesion of the ventral horn of one side in the cervical enlargement.

Bilateral brachial monoplegia is due to nueritis from lead-poisoning or to crutch pressure.

Crural monoplegia is rarely due to cerebral lesion. It may be due to disease of the anterior horn of the cord (*flaccid type as in poliomyelitis*) or to a localized lesion in the lateral column of the cord (*spastic type*) or to peripheral neuritis. A pelvic tumor may cause crural monoplegia by pressure on the nerves.

Facial monoplegia may be due to a cortical lesion in the anterior central convolution. It may be nuclear in origin. It may be due to a lesion affecting the facial nerve during its course through

the pons, within the temporal bone, or after leaving the stylomastoid foramen. If the lesion is in the cortex the paralysis is spastic and on the opposite side from the lesion. If nuclear or infranuclear, the paralysis is flaccid and on the same side as the lesion; in this case there is marked muscular atrophy. Bell's palsy, peripheral facial neuritis, is a common cause of the flaccid type.

If the lesion is central, that is supra-nuclear, the eye can be closed and the forehead wrinkled; if the lesion is nuclear or infranuclear, the orbicularis and frontalis are paralyzed and will atrophy.

In central lesions the paralyzed facial muscles are spastic and the mouth pulls toward the affected side. In peripheral lesions the mouth pulls toward the sound side by the unopposed action of the healthy muscles. The expressionless appearance of the paralyzed side in lower neuron facial paralysis is very distinctive. It is due to the disappearance of the expression wrinkles commonly present.

Most central facial paralyses are associated with hemiplegia, the face, arm, and leg of the same side being involved. Rarely does facial monoplegia occur except from peripheral causes.

To locate with accuracy the part of the facial nerve which is the site of a peripheral paralysis, examine the sense of taste in the anterior two-thirds of the tongue. If this is lost or diminished, the lesion must be between the genicular ganglion and the point where the chorda tympani is given off. If the sense of taste is preserved the lesion is either central to the genu or peripheral to the point where the chorda tympani leaves; it is usually peripheral. Fracture of the temporal bone may obstruct the facial. But commonest of all paralyzing factors is peripheral neuritis due to exposure to cold, followed by diffuse rheumatic neuritis.

SENSORY DISTURBANCES

The senses to be examined are Sight, Hearing, Taste, Smell, Touch (*including Pressure and Contact*), Temperature (*Heat and Cold*), and the Muscular, Articular, and Tendinous senses, all of which are **special** senses, and the sense of Pain, which is a general sense. All the special senses are mentally referred to some outside object or condition while the general sense of pain is sensed as arising within the body. Other general sensations such as hunger, thirst, well-being, sex, etc., can be examined only subjectively through the statements of the patient and have little diagnostic significance.

Examination of **vision** is properly the work of a specialist and abnormalities of vision commonly signify disease, functional or organic in the eye, the optic nerve, or the optic pathway within the brain, or abnormalities of the motor nerves of the eye (*oculomotor, trochlear, abducens*).

Examination of **hearing** may be done easily by holding a watch lateral to one ear while the other is covered and noting whether the sound can be distinguished at a normal distance. Test each ear separately. If deafness is present a watch or tuning fork placed against the temporal bone above the ear will distinguish between nervous and aural deafness. If the sound is conducted through the bone and heard distinctly while contact is maintained with the bone but lost as soon as contact is broken, the deafness is in the ear or Eustachian tube, whereas if bone conduction does not produce sensations of sound the acoustic nerve is involved.

The commonest causes of deafness are changes in the middle ear or occlusion of the Eustachian tube, often arising from an extension of naso-pharyngeal catarrh.

Nervous deafness may have its cause anywhere along the course of the acoustic nerve, in the acoustic nuclei within the brain-stem, in the ascending nucleo-cortical auditory pathway, or in the cortex of the temporal lobe. Tumor or abscess involving the inferior colliculi may produce deafness.

Lesion of the left temporal cortex may produce word deafness, inability to distinguish words although the sounds are heard. Lesions of the right temporal cortex may produce only deafness of the left ear. It should be remembered that many cases of nervous deafness are hysterical, comparatively few organic, and that the latter, when they occur, are likely to have followed trauma. Tumors, hemorrhage, fractures, and violent concussions at the base of the brain may affect the auditory nuclei and produce deafness. Syphilitic meningitis in the adult and epidemic cerebro-spinal meningitis in children frequently cause deafness.

In the majority of cases of nervous deafness there has been an extension of middle-ear disease into the labyrinth. Deafness from the otitis media sequel to scarlet fever operates in this way. Injury to the petrous bone, tumor, hemorrhage, or inflammation of the labyrinth, or certain drugs like quinine and the salicylates, may be responsible. Meniere's disease associates labyrinthine deafness with changes in the semicircular canals, producing marked vertigo and deafness.

The differential diagnosis of deafness requires painstaking search sometimes. Hysterical deafness can usually be identified by the fact that it is incomplete, some notes being clearly audible, that it is inconstant, sometimes being less marked than at others, that it may suddenly disappear or shift from one ear to the other, and that there are other hysterical stigmata. It is well to remember that hysteria may very closely simulate almost any disease in the calendar.

Tinnitus aurium is a general term applied to a wide variety of noises which have no foundation in actual sound-waves. They may be purely subjective or may develop from abnormal conditions in the middle ear, labyrinth, semicircular canals, acoustic nerve, or cortex. Middle-ear catarrh, tympanic disease, syphilis, brain tumors, meningitis, Meniere's disease, arteriosclerosis, anaemia, and many other conditions, may be accompanied by tinnitus aurium. Its causes are so various and so numerous that it has little diagnostic significance.

Examination of the Sense of Taste.

The tongue is protruded and kept so while drops of various solutions are placed on the anterior and posterior surface of the dorsum of the tongue on either side of the median line. It is important to test both sides because disturbances of taste due to nerve lesions are commonly unilateral. Both the anterior and posterior portions are examined because the anterior two-thirds of the tongue receives its taste fibres through the chorda tympani and the posterior one-third through the glosso-pharyngeal.

A solution of quinine may be used for the bitter taste; sugar for sweet; sodium chloride for salt; vinegar for acid. Usually the use of a sugar solution alone is enough to determine whether taste is normal or impaired. The above are the four primary taste sensations; most of the so-called "taste" of food is in reality smell, as may easily be discovered by closing the nostrils and trying to taste volatile substances, like vanilla, which have a distinctive odor commonly considered as taste.

Ageusia. Lack of taste may be due to excessive furring of the tongue, to protracted dryness of the tongue as in prolonged deprivation of water, to injury of the surface of the tongue by acids, hot drinks, etc. In such cases it is bilateral and general.

Unilateral and localized ageusia is due to disease either of the chorda tympani (*anterior two-thirds of tongue*) or the glosso-

pharyngeal (*posterior third*). The chorda tympani accompanies the lingual branch of the trigeminal to the tongue and a loss of taste accompanied by loss of tactile sense in the tongue suggests a lesion of this peripheral nerve combination. Tympanic disease or injury may involve the chorda as it traverses that cavity, in which case the general sensibility of the tongue is not necessarily impaired. Fracture of the temporal bone may injure the chorda. In the facial canal the chorda for a time accompanies the facial nerve, so that disease or injury within the canal, or involving the geniculars ganglion, will abolish taste on that side. Finally, brain lesions and hysteria may affect taste.

The Sense of Smell.

The Sense of Smell requires the integrity of the olfactory nerve, bulb and tract, and the olfactory portion of the brain, and also depends upon the condition of the olfactory (*pituitary, Schneiderian*) mucous membrane in the upper part of the nasal cavity. Agitation of the hair-like projections from the olfactory cells, which arise above the mucous surface, can only be accomplished by vibrating particles of volatile matter when these have free access to the nerve-ends. A membrane heavily coated with mucous secretion, or a mal-nourished membrane, or one inflamed and dried, prevents the imparting of vibrations properly to the nerve ends and interferes with smell.

To test the olfactory sense use such substances as peppermint, oil of cloves, or musk, in small containers which can be opened and closed at will. Remember that pungent vapors affect the trigeminal rather than the olfactory nerve.

Anosmia is loss of sense of smell; **hyperosmia** is increased senstitiveness to odor; **parosmia** is a perversion of the sense of smell so that odors are wrongly interpreted or improperly identified.

Anosmia is most commonly due to disorders of the nasal mucosa but may occur in hysteria or injuries to the skull affecting the olfactory bulb or tract. Anosmia may be due to paralysis of the trigeminal because of the deficient secretion and resulting dryness of the mucosa. There is a congenital form of anosmia due to imperfect developement of the olfactory nerve mechanism.

Tactile Sense.

Since it is necessary to accept the patient's statements as to his sensations it is essential that every precaution should be taken to

avoid deception, either intentional or unconscious. For examination of the skin blindfold the patient and ask him to state at once when he perceives the sensations which are to be elicited, using the word "Yes".

Avoid any verbal suggestions during the examination; let the patient respond to feelings rather than to words. Note the speed with which the response follows the stimulation. Normally, 1-10th of a second is enough; in disease the response may be delayed as long as 10 seconds.

When testing tactile, pain, and temperature sensations the area in which abnormalities are found should be carefully marked, as the extent and location of the disturbance may have a definite diagnostic value, pointing to the site of the causative condition. In some cases the entire body must be carefully gone over, a procedure which is irksome to the busy practitioner but which the specialist will not shun.

For testing the sense of touch, including the senses of contact and pressure, a simple instrument, the esthesiometer, may be had, consisting practically of a pair of dividers with blunt points. Ordinary compasses with their points protected by adhesive tape, or even a hairpin may be employed. The points are placed upon the skin with points far enough apart to be recognized as two separate contacts and are then brought closer together until they are no longer separately recognized but feel like one. Thus tactile discrimination is tested. Considerable variation in tactile discrimination from the distances given in the table below as usual, may be quite compatible with health. If the distances are twice as great as those given they may be considered abnormal.

Tip of tongue	1/25 in.
Tip of fingers	1/12 in.
Lips	1/8 in.
Dorsum of fingers	1/4 in.
Tip of nose	1/3 in.
Toes, cheeks	1/2 in.
Neck	1 2/5 in.
Forearms, leg	1 3/5 in.
Back	2 1/2 to 3 1/4 in.
Arm, thigh	3/4 in.

To test the sense of **contact** use the tip of a finger, the head of a pin, or a small cone of cotton; draw it lightly over the skin

and ask the patient to answer at once when he feels the contact. If the touches are rhythmically applied, miss one occasionally to determine whether the response is mechanical. Compare symmetrical parts.

Test the power of localization by touching a spot and asking the patient to put his own finger on that spot. In this test allow for some variation for inexperience; if the power of localization is good the accuracy of the patient will improve with practice.

To examine the pressure sense, which is the other element of tactile sensibility, the patient must lie down in such a position that muscular effort is eliminated and relaxation secured. Two similar objects are used, differently weighted; these are laid upon a part of the body and the patient is to distinguish which is the heavier. This sense is due to the displacement of the skin to differing degrees by different weights and is not to be confused with the muscular sense, which records the amount of effort required to lift an object. The muscular sense is active, the pressure sense passive; they travel through the central nervous system by different channels. Pressure sense is most acute on the brow, temples, forearm, dorsal surface of hand, and abdomen. It is least acute on the back and thighs; unless differences in weight are very marked, failure to discriminate correctly on the back has no significance.

Temperature Sense.

To examine this sense use test tubes filled with hot and cold water. Touch the surface with one and then the other and find out if the patient knows which is which. Temperatures of 60° to 65° should feel cold, those of 85° to 95° warm. Once in a while will be found a reversal; warm will be felt as cold and cold as warm. In some instances moderate degrees of heat and cold will be painful.

Pain Sense.

The pain sense may be absent, normal, or excessive. A sharp pointed instrument, a pin, needle, or pen point may be used. Pain conduction may be excessively slow, requiring several seconds for registration. Attention may first be called to abnormality of the pain sense when a wound, ordinarily of a painful nature, fails to be perceived for a markedly long interval or at all. Thick, calloused portions of the skin do not readily indicate pain conduction because the insensitive extra layers prevent the impression from reaching the nerve ends.

Muscular Sense.

Have patient blindfolded and put weights in his unsupported hands. The objects should be alike in size and shape but differ in weight. The amount of muscular effort required to lift or support them is registered through the sensory nerve terminals in the muscle ends and transmitted by the afferent nerves through the posterior columns of the cord. Weights may be placed upon the unsupported foot as well as the hands, to test the weight sense conduction through the lower segments of the cord as well as the upper.

Articular and Tendinous Sense.

These are tested together. Have the patient blindfolded and supine, then taking hold of a limb move it first in one way, then in another, asking the patient to duplicate the motion with the other limb. In paralysis, of course, this test cannot be made. Place one limb in a certain position and have patient describe that position.

Ataxia. This is a lack of co-ordination in standing, walking, or other voluntary movements. The maintenance of the equilibrium of the body during station and locomotion depend upon the muscular sense, which tells the amount of strength which has been and must be employed, the articular and tendinous senses, which record the position of the various parts of the body and their progressive changes of position, and to a lesser extent upon sight and touch.

To examine the upper extremities for ataxia, have the patient close his eyes and ask him to touch the tip of his nose with his finger, or to touch the tips of the opposite fingers together. If he succeeds measurably well, co-ordination is good. Remember that the first attempts may be slightly off because of inexperience in this movement.

To test for ataxia of the lower extremities, have the patient stand with closed eyes and heels together and observe the swaying of his body. A normal person will sway about one inch. An ataxic patient will sway further, and increasingly, until he may fall unless aided. This is static ataxia and the symptom is called "The Romberg symptom"—the test "the Romberg test." To test for **locomotor** ataxia, ask the patient to walk along a straight seam of carpet or any visible straight line. If he is unable to do so he is ataxic. If unable to walk, the patient may be tested in bed by ask-

ing him to imitate movements, or with closed eyes to touch the great toe of one foot to a designated spot on the other foot or leg. It is only fair to let him practice a little.

Cerebellar ataxia is a special type due to disease of the cerebellum, usually the vermis. It is characterized by a peculiar reeling, drunken gait, although in bed and relieved from the necessity for maintaining equilibrium the patient is able to perform movements according to direction. Loss of equilibrium is the outstanding feature.

Conclusions from Sensory Disturbances.

While sensory disturbances alone, without associated symptoms, are seldom sufficient evidence on which to base a positive diagnosis, taken in conjunction with accompanying phenomena they often prove to be the pivotal factor in the location of a nerve lesion. For example, anesthesia accompanied by flaccid, atrophic paralysis, both corresponding in distribution to that of a single spinal nerve trunk, indicates a peripheral nerve lesion, whereas the same paralysis without sensory involvement will almost certainly be due to a limited lesion in the ventral gray matter of the cord where the motor and sensory elements are dissociated.

Anesthesia ordinarily means loss of tactile sensibility. It may, however, be applied to loss of any form of sensation. It may be purely functional or may arise from organic changes; in the former case it is usually transient and its distribution may not correspond precisely to the known distribution of any certain nerves, tracts, or cell groups; in the latter instance, it is more or less stable and its distribution enables the examiner to determine with reasonable accuracy the location of its cause.

The more important conditions causing anesthesia are, in general, hysteria and traumatic neuroses; cerebral lesions such as cause hemiplegia; diseases of the posterior roots, or of the posterior horns or columns of the cord, especially locomotor ataxia; pressure on the cord; peripheral neuritis; leprosy.

Hemianesthesia is a loss of tactile sensibility of one lateral half of the body. More often the result of hysteria than anything else, it generally affects the left half of the body and ends with geometrical exactness at the midline; this may be accompanied by loss of sight, hearing, taste, or smell on the same side. Hemiplegia due to lesion in the internal capsule may be accompanied by hemi-

anesthesia of the same side, when the lesion extends into the posterior third of the retrolenticular limb of the capsule. Hemiplegia and hemianthesia of the same side with oculomotor paralysis of the opposite side indicate a lesion of the cerebral peduncle at the level of the oculomotor nucleus. Similarly, hemiplegia and hemianesthesia of the same side plus crossed facial paralysis of the flaccid type indicate a lesion of the pons involving the facial nucleus or facial nerve after leaving the nucleus. A lesion in the upper part of the pons may also cause anesthesia of one side of the body with anesthesia of the opposite side of the face (*crossed hemianesthesia—rare*).

In multiple sclerosis or hemichorea, hemianesthesia may be due to lesion of the optic thalamus or to a large cortical or subcortical lesion, but this also is rare.

A unilateral lesion of the spinal cord will develop an incomplete hemianesthesia (*below the level of the lesion*) with partial hemiplegia of the opposite side—that is, the side on which the lesion is situated.

Bilateral anesthesia affecting only the lower extremities is usually due to a transverse lesion of the cord, such as hemorrhage into the cord, spinal meningitis, tumor, myelitis, or locomotor ataxia, or may be caused by injury to the cord as in fracture of the vertebrae or their collapse due to Pott's disease. If bilateral anesthesia is general it is commonly hysterical or due to a traumatic neurosis. In hysteria, a triangular area on the scrotum and the skin over the external genitals will retain sensibility.

Irregular anesthesia is due to hysteria or neuritis most commonly. Hysterical anesthesia may shift from place to place and does not usually follow the distribution of a particular nerve, while that due to neuritis is more or less persistent and follows the distribution of one or more nerves.

Hyperesthesia. This is excessive sensitiveness to tactile and other impressions. It indicates a heightened irritability of the sensory nerve elements. It is common in hysteria, being located in certain special areas called "hysterogenic zones". In neurasthenia there may be hyperesthetic spots along the vertebral column and upon the scalp and chest. In some cases there is a general hyperesthesia of a mild character.

Neuralgia of any nerve may be accompanied by hyperesthesia in that area. Gouty patients, or women in the menopause may have

excessively tender scalps. Hyperesthesia (*general*) occurs early in rachitis and is usual in many febrile conditions such as typhoid, and epidemic influenza; it may occur in anemia. The paralyzed side in hemiplegia may be hyperesthetic.

Unilateral lesion of the spinal cord develops a narrow zone of hyperesthesia just above the zone of anesthesia on the side of the lesion.

Referred Tenderness of Visceral Disease.

Among the most important diagnostic considerations of hyperesthesia are the referred tenderness from visceral diseases. The afferent nerves arising in the viscera possess a lower degree of pain sensibility than do the cerebrospinal nerves; they connect with the latter in the spinal and cranial nerve ganglia by the intermediation of the cells of Dogiel and, if stimulation be sufficient, may transfer afferent stimuli to the related spinal or cranial nerves; these are mentally interpreted as coming from the cutaneous sensory area from which the spinal or cranial nerve usually carries sensory impressions. If sufficiently intense these transferred impressions are registered as pain; they may be referred to the remoter terminals of the nerve which carries them, as when ovarian disease develops a referred pain in the inner side of the thigh. When actual pain is not present there may be a similar referred tenderness.

Ovarian disease may show a tender area on the front of the thigh; uterine disease, by some unexplained pathway, often develops a tender mammary gland. Angina pectoris and liver disease may show a pain entending down the arm, the left arm in angina, the right in liver disorders. Dyspepsia and constipation may produce a left side pain at the level of the ninth and tenth ribs. The sharp pain in the tenth left interspace, about two inches from the mid-spinal line, which is associated with gastric ulcer, is well known. The pain of Dietl's crisis (*renal calculus passing the ureter*) radiates into the testes. Hip-joint disease is characterized by pain in the knee.

Pain or tenderness in any locality, unless explainable by the discovery of local disease, should lead to careful consideration of the visceral connections of the nerves which supply that surface area, for the discovery of possible visceral disease, of which this tenderness may be the first indication.

Disturbances of the **temperature sense** occur especially in syringomyelia, because the spinal gray matter contains the pathway for temperature conduction, and to a lesser extent in locomotor ataxia and in lesions of the medulla.

Hyperalgesia is excessive sensibility to pain; **analgesia** is loss of pain sense. The latter is found especially in syringomyelia, Morvan's disease, and hysteria; occasionally in syphilis.

Loss of the Muscular, Articular, and Tendinous Senses is due to an interruption of the sensory conducting tracts for these impressions and constitutes ordinary ataxia as distinguished from cerebellar ataxia. It is one of the outstanding features of locomotor ataxia and is found also in transverse diseases of the cord, syringomyelia, Friedrich's ataxia, ataxic paraplegia, and in cortical lesions and lesions of the cerebral peduncles, colliculi, or pons.

Delayed Conduction. An abnormal lapse of time between stimulation and response, especially to pain stimuli (*8 or 10 seconds instead of the normal 1/10th second*) may occur in locomotor ataxia and in peripheral paralyses.

THE REFLEXES

Since each reflex involves an arc including an afferent nerve, a group of motor cells in the cord or medulla, and an efferent nerve leading to a muscle, it follows that examination of a reflex is intended to determine the integrity of the reflex arc. Interruption anywhere in the arc may abolish the reflex. In actual practice, the most important fact established by eliciting a normal reflex is the integrity of the spinal cord segment through which that reflex is known to pass. Negative evidence; that is, diminution or abolition of a reflex, is less conclusive since it might be due either to lesions affecting the ventral horn or to deterioration of either afferent or efferent peripheral nerves, or to general debility of the nervous system. When diminution of reflexes is caused by peripheral nerve disease it is usually accompanied by both paralysis and anesthesia.

Exaggeration of reflexes, a too vigorous response to ordinary stimuli, indicates the integrity of the reflex arc and shows either heightened excitability of the motor cells or, more commonly, an interruption of the governing influence of the upper neurons upon the lower.

The reflexes to be examined for diagnostic purposes are: (a) the **cutaneous** or **superficial**; (b) the **tendinous** or **deep**; and (c) certain **organic** reflexes.

The entire reflex action usually occupies from 1/10th to 1/12th of a second. Reasonable variation may be compatible with health but a too marked variation means delayed conduction, usually in the spinal cord.

To elicit the cutaneous reflexes, stroking or pinching the skin should induce contraction of the adjacent muscles. The deep reflexes are tested by tapping the tendon, whereupon the attached muscle should contract. The organic or visceral reflexes cannot be tested but may be observed by noting the response to stimuli arising within the body; as the function of defacation which is a reflex response to the presence of faecal matter in the rectum, or urination, excited by fullness of the urinary bladder.

The Superficial Reflexes are:

Scapular—Irritate the interscapular region and the scapular muscles will contract. C7, 8, T1.

Epigastric—Roughly stroke the chest downward from the nipple and the epigastric muscles will contract. T5, 6, 7.

Abdominal—Irritation of the abdominal wall below the ribs will cause muscular contraction on the irritated side. T8 to L1.

Cremasteric—The testicle and scrotum will be drawn upward when the inner and upper part of the thigh is stroked. L1, 2, 3.

Gluteal—The gluteal muscles will contract following an irritation of the skin over the gluteal region. L4, 5.

Plantar—Stroke the sole of the foot and the leg is jerked upward. S2, 3.

Babinski Toe Reflex—Stroking the inner side of the sole of the foot from heel to toe, in normal subjects, includes plantar flexion of all the toes. In young infants, before the pyramidal tracts are myelinized, dorsiflexion of the great toe occurs instead; this dorsiflexion occurs also in certain organic diseases.

Reflexes depending upon the condition of the medulla oblongata rather than the cord are:

Conjunctival Reflex. Touch the conjunctiva and the eyelids will suddenly close; the afferent pathway is the trigeminal, the efferent the facial nerve.

Pupillary Skin Reflex. Stroking the skin of the chin or the neck causes dilation of pupils.

Palatal. Touching the mucous membrane of the palate causes the palate to be drawn up. The afferent nerve is the glossopharyngeal, the efferent the vagus or spinal accessory.

Diagnostic Value of Superficial Reflexes. Their presence is of value as indicating the absence of serious disease in the spinal cord or bulbar segments through which they pass. Their absence is to be interpreted cautiously, as it may not indicate actual disease.

Presence of the Babinski reflex is common in disease of the lateral columns of the cord but it is absent in poliomyelitis and hysteria. Any superficial reflex may be lost in hysteria.

The Deep or Tendon Reflexes.

Those commonly examined, together with the segments through which they pass are:

Jaw Jerk. Place a finger on the chin, have the patient open his mouth but not too widely, deliver one or two sharp percussion strokes upon the finger. If the reflex is working the mouth will suddenly close by contraction of the muscles innervated by the trigeminal. (*Not present in health.*)

Elbow Jerk. Draw the arm outward from the body and grasp the crook of the elbow in such a way that the forearm will hang downward at right angles to the upper arm. Then with a percussion hammer tap the arm just above the olecranon process. The forearm will be extended by the contraction of the triceps. This tests the integrity of segments C5, 6, and 7.

Wrist Jerk. The above segments may also be tested by letting the wrist hang down as in wrist-drop and striking the extensor tendons just above the wrist joint. The hand will perform a movement of extension.

Knee Jerk. The leg should hang limply at right angles to the thigh, over the edge of a table or swung from the forearm of the examiner, who has pushed his hand under the crook of the knee and rested it upon the opposite knee. With the leg swinging free, sharply tap the patellar tendon just below the patella. An abrupt forward jerk of the leg and foot should follow if the reflex is normal. If the patient cannot sit up the knee may be raised and supported by the examiner's hand.

In cases where the knee jerk is absent it is sometimes possible to elicit a jerk by asking the patient to clench his fists tightly or to

hook his fingers together and pull hard. This effort, either by increasing general muscular tension or by lessening cerebral inhibition, may bring out a knee jerk.

In some cases of exaggerated knee jerk it may be possible to establish a "knee clonus" similar to ankle clonus by extending the leg and pressing firmly and suddenly downward on the patella.

The knee jerk works through the second and third lumbar segments.

Ankle Jerk. Extend the leg and grasp the foot in the hand, bending the foot upward so as to stretch the tendo calcaneus. Strike the tendon sharply and the calf muscles will contract, extending the foot on the leg.

If the pressure upon the sole of the foot be suddenly exerted and then maintained, there may ensue a rhythmic series of contractions of the calf muscles, causing the foot to jerk repeatedly against the pressing hand. This is called "ankle clonus" and may be elicited under conditions which produce an exaggerated ankle jerk.

Light Reflex. Normally the pupil will contract in the presence of light. Cover one eye and bring a light near the other, and observe whether the pupil contracts. Or cover both eyes and then uncover one in the presence of strong sunlight. The eye thus uncovered should show a definite contraction of the pupil. The afferent pathway for this reflex is by way of the optic nerve, the efferent pathway by the oculomotor.

Accommodation Reflex. The pupil should diminish in size when looking at near objects and increase when used in distant vision. This is tested by asking the patient to direct his gaze alternately to a near and a distant object; for example, to a pencil held near the eye and then to a distant church spire.

Diagnostic Conclusions from the Deep Reflexes.

The presence of normal deep reflexes indicates the integrity of the segments through which they pass. Their exaggeration may occur in heightened excitability of the cord but more commonly suggests a lesion of the brain or of the lateral columns of the cord interrupting the pyramidal tracts. Spastic paralyses show exaggerated reflexes, a characteristic of the upper neuron type of paralysis. Absence of the deep reflexes of the upper extremity is of

much less significance than absence of the lower ones, as the former may be absent in health. The jaw jerk is never elicited under normal conditions. The presence or exaggeration of jaw, elbow, and wrist jerk, is of more importance than failure to elicit them.

The ankle jerk is usually present in health but ankle clonus is never developed except as a consequence of the same conditions as those which produce exaggerated knee jerk.

The knee jerk is abolished by any condition affecting the integrity of the reflex arc. Peripheral neuritis, diseases of the posterior roots and columns, such as locomotor ataxia or Friedrich's ataxia; the ventral horn group of diseases affecting the lumbar region, as poliomyelitis, Landry's paralysis, or transverse myelitis involving the second and third lumbar segments. The knee jerk is absent in apoplexy and in injuries to the cord immediately after the shock, in epilepsy immediately after the convulsion, and in spinal meningitis. In apoplexy it returns when the shock effect has subsided and is followed by exaggerated jerk during the post-apoplectic hemiplegia.

In many neurasthenic subjects the knee jerk is permanently feeble or abolished. It is well not to be too hasty in postulating organic disease because of absent reflexes.

Exaggerated knee jerk shows that the reflex arc is intact and that the excitability of the cord has been heightened or that the pyramidal tracts are interrupted and their normal inhibiting influence diminished or lost. Among the conditions which will so interrupt the pyramidal tracts are: apoplectic hemiplegia, shortly but not immediately after the seizure; cerebral paralysis of children; hereditary cerebellar ataxia; general paralysis of the insane. The lesions affecting the lateral columns of the cord are lateral sclerosis and amyotrophic lateral sclerosis. Transverse myelitis, pressure or hemorrhage of the cord, if above the lumbar segments, will cause exaggerated knee jerk, on one side if the lesion is unilateral and on both sides if bilateral.

Hysteria, neurasthenia, tetanus, strychnine poisoning, or rheumatic arthritis may exaggerate the knee jerk.

Organic Reflexes.

Defecation. Diseases of brain or cord above the lumbar region may cut off cerebral control of the reflex of defecation and result in

incontinence of faeces, especially for fluid faeces. This may occur in any of the following conditions: Apoplexy, uraemia, epileptic coma, meningitis, insolation, hydrocyanic poisoning, typhoid fever, the typhoid state, cholera morbus, cholera infantum, Asiatic cholera, dysentery, myelitis and other diseases of the cord, the grave form of chorea, tetanus and strychnine poisoning and other diseases accompanied by convulsions.

Many of these conditions are due to excessive irritation of the peripheral nerve ends of the reflex mechanism but this is not usually enough to produce incontinence unless accompanied by a weakening of cerebral control. In practice, incontinence of faeces is met with oftenest in typhoid fever.

Urination. Incontinence of urine, the voiding of urine reflexly without, or against, the consent of the will, may occur in any condition which interrupts the cerebral control over the sacral segments of the cord. Cerebral lesions and transverse lesions of the cord are the commonest causes. Bladder symptoms are more common in myelitis and locomotor ataxia than in poliomyelitis, multiple neuritis, and amyotrophic lateral sclerosis.

Incontinence, especially during sleep (*enuresis*) may be due to an irritation affecting some part of the nerve mechanism; cystitis, ascarides, vesical calculus, phimosis, contracted meatus, and concentrated or diabetic urine are among such irritants. Over-fatigue, followed by over-sound sleep, may lead to enuresis in those with weak nervous systems.

Dysphagia. Difficult or painful swallowing may attend many conditions including painful or irritating diseases of or near the mouth, pharynx, or esophagus. Spasm or paralysis of the pharynx or esophagus may interfere with swallowing. Pain may be so severe as actually to inhibit the act of swallowing without direct interference with any of the nerves.

Internal Organic Reflexes. Most of the internal functions of the body are regulated by means of reflexes the evidence of which comes to the surface only indirectly. The action of the respiratory reflexes can be easily determined, as can the cardiac reflexes by means of the pulse. That series of reflexes whose activity begins at the cardiac end of the stomach and proceeds throughout the remainder of the alimentary tract, the accessory digestive reflexes which control the secretion of the glands emptying into the diges-

tive tract, the complicated vasomotor reflexes throughout the body, the reflex acts by which the nervous system influences the ductless glands, are almost beyond the reach of examination.

The integrity of the renal nerve mechanism may be inferred from the results of urinalysis, but in abnormal conditions of the kidney it is difficult to dissociate purely nervous causes from blood-pressure abnormalities or the action of toxins.

In general, abnormalities of the internal organ reflexes may be inferred from symptoms of abnormal action of the organs.

SUMMARY OF LOCATIVE DIAGNOSIS OF NERVE LESIONS

A good plan is to prepare a written table of symptoms to be checked against the known functions of the different parts of the nerve system. The normal performance of certain functions will at once rule out organic disease of the neurons (*cell-bodies and axons*) hrough which these functions are performed. For example, complete absence of any sensory involvement in a given case will at once eliminate from consideration the entire afferent portion of the nerve system. Furthermore, because the motor and sensory elements of the spinal nerves travel in the same trunks and are affected by the same conditions, the absence of sensory involvement also rules out peripheral (*spinal*) nerve lesions except possible radicular lesions affecting the ventral roots alone. Flaccidity of the paralyzed muscles, with atrophy and abolished reflexes, marks the case as one of lower neuron lesion rather than upper—and it becomes certain that the lesion lies either in the ventral horn of the cord or the ventral root. The ventral roots are usually affected singly when the lesion does not involve the cord itself; hemorrhage, tumor, or injury rarely affects several superimposed segments at once unless extensive enough to profoundly affect the cord. Therefore a distribution extending over several adjacent neuromeres argues for ventral horn rather than radicular lesion.

If, on the other hand, a paralysis without sensory involvement is of the spastic type, with little or no muscular atrophy, and the reflexes are exaggerated, it is easy to conclude that the upper neurons are interrupted. This interruption may be anywhere from the cortical cells of origin of the pyramidal tract fibres, down through their course in the corona radiata, internal capsule, mid-brain, pons, medulla, or lateral funiculus of the cord. As in amyotrophic lateral sclerosis it may affect chiefly the very terminals of

the pyramidal tract fibres as they communicate with the ventral horn cells. This calls for segmental diagnosis, in which the following briefly stated facts will be of service.

1. **Hemiplegia** is commonly of cerebral origin. If of spinal origin (*lateral column lesions*) the paralysis will be an incomplete hemiplegia of the spastic type below the level of the lesion and (*probably*) a narrow band or zone of atrophic, flaccid paralysis at the level of the lesion because of involvement there of the ventral horns as well as the lateral column.

2. The **location** of the cerebral lesion in hemiplegia may be determined by study of the precise nerve functions interrupted, while the **nature** of the lesion may be inferred from the mode of onset and the associated symptoms. The following symptom groups are commonest:

(a) **Hemorrhage, embolism** or **thrombosis.** Preceded by high blood-pressure and apoplectic symptoms, sudden coma or convulsion followed by hemiplegia. Hemorrhage follows arteriosclerosis and miliary aneurisms; embolism left-side heart lesions; thrombosis depends upon arteriosclerosis or syphilitic endarteritis.

(b) **Cerebral syphilis.** History of severe and persistent headache, vertigo, nausea, vomiting, epileptiform convulsions, and apoplectiform attacks, followed by various paralyses, especially oculomotor paralysis.

(c) **Brain abscess.** History of injury to the head or of suppurative disease of the ear, nose, or lung, followed by headache, vomiting, vertigo, delirium or stupor, optic neuritis, tenderness of the scalp, slow pulse and perhaps irregular fever.

(d) **Brain tumor.** Headache, vertigo, vomiting (*often projectile*) optic neuritis, and mental defects may precede the hemiplegia and are of slow and gradual development. Headache, vertigo, and "choked disk" strongly suggest brain tumor.

(e) **Hysteria** is recognized by associated symptoms, the stigmata of hysteria, such as anesthesia, contraction of the visual fields, etc. The age of the patient may suggest the unlikelihood of organic brain lesions. The outstanding feature of hysterical hemiplegia is that it is likely to include some completely contradictory factor.

3. Temporary or transient hemiplegia may be due to embolism or thrombosis and may presage a more severe attack; or it may be due to uraemia.

4. In young adults, hemiplegia, unless hysterical, should suggest the possibility of syphilis.

5. Ordinary hemiplegia (*face, arm and leg of the same side*) is commonly due to a lesion in the knee and posterior limb of the internal capsule.

6. If in the above the arm is paralyzed to a much greater degree than the leg and there is little or no anesthesia, the lesion is in the anterior two-thirds of the posterior limb of the capsule.

7. If in the above the leg is more paralyzed than the arm and there is hemianesthesia of the same side, with hemiopia and disturbances of hearing, the lesion is well back in the retrolenticular limb of the capsule, where the optic and auditory radiations traverse it close to the ascending afferent tracts from the cord.

8. Hemiplegia plus hemiathetosis or hemichorea indicates a lesion in the optic thalamus encroaching upon or invading the internal capsule.

9. Hemiplegia of one side with oculomotor paralysis (*lower neuron type*) of the opposite side locates the lesion as being in the cerebral peduncle where it involves the oculomotor nuclei or the nerve after leaving the nuclei. The pyramidal tracts are here undecussated but will cross lower down, so that their interruption anywhere above the medulla paralyzes the half of the body opposite to the side of the lesion. The oculomotor pathway does not cross after leaving the nuclei.

10. Hemiplegia with paralysis of the face (*lower neuron type*) on the opposite side indicates a lesion in the lower part of the pons. The uncrossed pyramidal tract is here involved by the same lesion which affects the nucleus of the seventh nerve or the nerve itself in its tortuous course through the pons.

11. Right hemiplegia with motor aphasia suggests a lesion in the third left frontal convolution.

12. Hemiplegia with anarthria and difficult swallowing locates a lesion in the medulla.

13. Oculomotor paralysis of one side with loss of weight sense and posture sense on the opposite side may be due to a tegmental lesion in the cerebral peduncle on the same side as the ocular paralysis.

14. If a paralyzed limb shows convulsive movements from time to time or if a convulsed muscle becomes paralyzed, it may be due to

a progressive cortical lesion (*tumor, localized meningitis, abscess, or small hemorrhage*) of that part of the cortex from which the limb is innervated.

15. A sense of pain, tingling, or motion, preceding a local spasm of an extremity (*Jacksonian epilepsy*) points to the location of the causative lesion in the cortex.

16. Paraplegia of the spastic or cerebral type is commonly due to a lesion of the motor tracts of the cord. To be caused by cerebral lesion, it would require bilaterally symmetric cortical lesions, a rare phenomenon.

17. Paraplegia of the flaccid or spinal type may be caused by lesions of the anterior horns or by peripheral neuritis. Rectal or bladder symptoms point to lesion in the substance of the cord.

18. Monoplegia may be caused by cerebral disease, spinal cord disease, or disease of the peripheral nerves. If cerebral, the lesion is almost always cortical because only in the cortex are the nerve supplies of the different parts of the body sufficiently dissociated for the one to be involved without others.

19. To distinguish between spinal cord and peripheral nerve disease as the cause of a monoplegia or localized paralysis:

If there is a history of cold or trauma, it is probably peripheral.

If the paralysis and anesthesia correspond to the segmentary representation in the cord, the lesion is in the cord.

If the paralysis and anesthesia correspond to the area of distribution of one or more spinal or cranial nerves, the lesion is peripheral.

20. If the tongue when protruded deviates laterally, one hypoglossal nerve is paralyzed. This suggests a bulbar lesion.

21. Anarthria, dysphagia, bilateral atrophy of the tongue, lips, palate, and throat muscles, point to bulbar lesion. Anarthria is not to be confused with aphasia, in which the muscular apparatus of speech is unaffected but the cerebral centers fail to function.

22. A purely motor aphasia is due to lesion in the third left frontal convolution (*cortical or subcortical*).

23. Paralysis of the muscles of mastication indicates a lesion affecting the mandibular division of the trigeminal.

24. Paralysis of the sternocleidomastoid and upper part of the trapezius is caused by lesions affecting the spinal portion of the eleventh cranial nerve.

25. Hemianesthesia of the skin and special sense organs is due to a lesion far back in the posterior limb of the internal capsule.

26. Partial hemianesthesia of one side of the body is often associated with partial hemiplegia of the opposite side in unilateral cord lesions.

27. Diseases of the cervical cord, if they produce sensory disturbances, will locate them in the fingers, hand and arm; those of the thoracic cord in the back, trunk, and thighs; those of the lumbar cord in the feet and legs.

28. In transverse lesions of the cord the anesthesia begins three or four inches below the lesion in the cord, because of the upward trend of the sensory root fibres.

29. Disturbances of taste in the posterior third of the tongue indicate involvement of the glossopharyngeal nerve; of the anterior two-thirds of the tongue, the chorda tympani. If coupled with tactile anesthesia the latter indicates lesion of the lingual branch of the trigeminal after it has been joined by the chorda.

30. In anesthesia of cortical origin the reflexes are preserved although the patient is unable to feel the touch which excites them.

31. Hemiopia may be caused by a lesion in the occipital lobe, the pulvinar of the optic thalamus, the superior colliculus, or one optic tract; if associated with hemianesthesia it is probably due to lesion in the retrolenticular limb of the internal capsule.

32. Word deafness is due to lesion of the first and part of the second temporal convolution.

33. The cerebellar type of ataxia, drunken, staggering gait with little or no ataxia of the limbs while lying in bed, signifies lesion of the vermis, usually a tumor. Often accompanied by headache, vomiting, vertigo, and optic neuritis—the latter especially significant of tumor.

34. Cerebellar ataxia with ocular paralysis, auditory disturbances, and paralysis of the muscles of mastication suggests a lesion of the corpora quadrigemina.

35. Certain parts of the brain when diseased do not give rise to definite motor, sensory, or other describable symptoms. These are the anterior portion of the frontal lobe, part of the temporal lobe, part of the inferior parietal lobule, the corpora striata, and the lateral lobes of the cerebellum. It is this absence of clinical evidence which has made it so difficult to determine the precise physiology of these parts.

CLINICAL DIAGNOSIS OF ORGANIC NERVOUS DISEASES

It is well to bear in mind that lesions in the central nerve system rarely affect a single tract or a single well-defined cell group to the exclusion of all others and that therefore clean-cut and typical symptom complexes are the exception rather than the rule. It is necessary in describing these diseases to set down the facts regarding classical or typically perfect cases, and to name some of the commonest variations from this type. It is understood, however, that in actual practice modifications and undescribed combinations will be frequently met with.

The best equipment for the neurological diagnostician is not so much a memory of typical symptom complexes as an exact knowledge of nervous anatomy and physiology, which will enable him after careful elicitation of all symptoms to **reason** directly to the exact location and probable nature of the disease. Certain of the commoner clinical pictures will be described, beginning with:

DISEASES OF THE SPINAL CORD AND MEDULLA OBLONGATA

These may be divided for convenience into the following groups:

(1) Anterior horn nuclei group—Anterior poliomyelitis type. Syndrome of muscular paralysis, lost reflexes, atrophy.

(2) Combined anterior horn and lateral column group—Amyotrophic lateral sclerosis type. Syndrome of muscular weakness, spasticty, atrophy.

(3) Central gray substance group—Syringomyelia type. Syndrome of pareses, atrophy, dissociation.

(4) Postero-lateral column group—Combined scleroses type. Syndrome of ataxia, spasticity.

(5) Diffuse disease of cord—Myelitis type. Syndrome of paralysis, spasticity.

(6) Ventro-lateral column group—Lateral sclerosis type. Syndrome of paralysis, spasticity, exaggerated reflexes.

(7) Posterior column group—Locomotor ataxia type. Syndrome of ataxia, lost reflexes, anesthesia.

(8) Secondary degenerations group—Hemiplegic type. Multiple sclerosis. Syndrome of spasticity, paralysis, unilaterality.

ANTERIOR HORN NUCLEI GROUP

Acute Anterior Poliomyelitis.

This is a disease of the anterior horn nuclei of the cord, with sudden paralysis of one or more limbs followed by muscular atrophy but without sensory disturbances. It occurs at all ages but especially in young children. It may be epidemic.

The disease usually invades the cervical segments first, spreads rapidly downward, then recovers (*except when early death occurs*) except for the lumbar segments, in which the ventral horn cells permanently atrophy. The resultant paralysis is usually, but not always in one lower extremity, less commonly in both lower limbs, occasionally quadruplegia is the permanent state.

Onset—Sudden, with mild fever (*100° to 102°*) lasting from one to four days, sometimes with vomiting, diarrhea, delirium and convulsions. Within from 24 hours to a week paralysis appears, often a diplegia, more commonly a paraplegia. Except in the presence of an epidemic the paralysis may be the first positive means of diagnosis.

After subsidence of the acute symptoms there may be pain in the back and legs for some days. There are rarely bladder or rectal symptoms. Sensation is retained throughout.

The paralysis of the affected limbs at first increases, then remains stationary for 1 to 6 weeks, then slowly improves for from 6 to 12 months, settling into a permanent condition. The affected limb is markedly atrophied, flaccid, cold and mottled, and the reflexes are absent. Foot-drop is common. The paralyzed limb does not grow normally, owing to the loss of the trophic influence of the ventral horn cells. It may develop contractures and various forms of club-foot.

Differential Diagnosis. From the cerebral palsy of children, which shows spasticity, exaggerated reflexes, unilateral paralysis, and no muscular atrophy. From myelitis and spinal cord hemorrhages by the presence in these latter of sensory disturbances and, if the lower cord is affected, vesical and rectal symptoms. Multiple neuritis rarely occurs in children, its onset is less abrupt, and there is sensory involvement.

Direct diagnosis of anterior poliomyelitis depends upon the age of the patient, the abrupt onset, the sudden and complete paralysis, the absence of spasticity, pain, and vesical and rectal symptoms, and the developing atrophy.

Prognosis. Without treatment, partial and limited recovery of the paralysis may occur. If recognized in the pre-paralytic stage, adjustment of cervical vertebrae will often abort the disease and prevent, or almost prevent, paralysis. After paralysis is established vertebral adjustment affords the surest means of restoring proper blood-supply to the atrophied ventral horn and thus insuring the maximum regeneration. Many complete cures are thus brought about.

In determining the relation of the diseased cord segments to the vertebrae, bear in mind that the cord is shorter than the neural canal and that the segments which correspond to the lumbar and sacral nerve roots lie internal to the last two thoracic and first two (*in children*) lumbar vertebrae.

Chronic Anterior Poliomyelitis.

Uncommon. May follow syphilis, lead-poisoning, or exposure in adult males. The extremities become gradually, but quite rapidly paralyzed, with atrophy and abolition of reflexes. No vesical symptoms and little pain. The absence of pain, tenderness, and anesthesia distinguish it from multiple neuritis.

Progressive Muscular Atrophy

(*Duchenne-Aran's disease*). May occur any time between the ages of 14 and 70 but is commonest from 25 to 45. Many severe, acute diseases seem to predispose but the etiology is uncertain.

This disease is characterized by muscular atrophy and gradual paralysis of the flaccid type, beginning in the fingers and extending upward. Commonly classified as a "muscular dystrophy" to distinguish it from muscular atrophy of spinal origin, although the only real distinguishing feature is that in progressive muscular atrophy, the wasting of the muscles precedes demonstrable atrophy of the nerves instead of following it. This should be considered as having origin in the cervical segments of the cord.

Begins with slight rheumatoid pains in the arm or shoulder, with numbness and a weary feeling. Atrophy then appears in one

hand and gradually extends upward. After three or four months the other arm usually becomes involved. Contractures develop in the wasted and paralyzed muscles and the characteristic "claw hand" develops.

From the shoulders the atrophy proceeds through the deep muscles of the back, then down to the hip and thigh.

The wasting may finally invade the neck, with paralysis of the diaphragm (*phrenic nerve*) resulting in death.

In this disease the paralysis follows and keeps pace with muscular atrophy. Sometimes the muscles are flaccid and the knee-jerk lost; the picture is then very similar to that of an extensive poliomyelitis. More often the knee-jerk is exaggerated and the muscles spastic though markedly atrophied; this may resemble amyotrophic lateral sclerosis.

There is no anesthesia but may be paresthesias and rheumatoid pains. Vasomotor symptoms, excessive sweating, and congestion of the affected parts are common. The sphincters are not involved but the sexual power may be impaired.

Diagnosis. To be distinguished from syringomyelia, multiple neuritis, and chornic anterior poliomyelitis. In syringomyelia there are sensory disturbances (*pain and temperature*) and trophic abnormalities. The onset of multiple neuritis is rapid and the pain severe; anesthesia occurs. In anterior poliomyelitis the onset is sudden, the paralysis soon reaches its height, and thereafter diminishes in extent rather than progresses. The atrophy follows instead of preceeding the paralysis. In progressive muscular atrophy the muscles affected are anatomically associated; in anterior poliomyelitis the muscles are physiologically associated.

Prognosis. Duration 2 to 30 years, average 10 years. Grows with remissions until fully developed and then remains stationary. Death occurs usually from lung disease due to paralysis of the respiratory muscles.

Progressive Hereditary Muscular Atrophy of Leg Type

(*Charcot-Marie type*). Occurs oftener in males than in females, usually before the age of 20. Apparently hereditary and of central or neuritic origin.

The muscles of the foot are first affected, the peronei, then the extensors of the toes, then the calcaneal muscles. The atrophy

extends to the thighs later; after some years the small muscles of the hand become involved, then those of the arm, except the supinator longus. There is no anesthesia, but pain and numbness. Fibrillary twitchings and the reactions of degeneration (*R.D.*) will be present. The course of this disease is long and protracted and it is considered incurable.

Progressive Bulbar Paralysis

(*Glosso-Labio-Laryngeal Paralysis*). A neuropathic diathesis seems to predispose. Syphilis, lead-poisoning, exposure, mental strain, and overuse of the talking muscles are frequent etiological factors.

The disease first affects the tongue, which cannot be normally elevated or protruded and upon which wrinkles appear. Anarthria appears, the chief difficulty being with the consonants l, r, and t. Weakness of the lips follows and the labials are uttered with great difficulty. Difficult swallowing develops and there is dribbling of saliva. The dysphagia applies first to solids and then to liquids, semisolids being easier to manage. Palatal paralysis gives the voice a distinct nasal tone. Finally the lower part of the face becomes paralyzed and motionless, with open mouth, while the upper part shows great anxiety and suffering. Pain and anesthesia are absent. Taste may be impaired.

Diagnosis depends upon the slow onset, the bilateral distribution (*centers in the medulla lie near the mid-line and are mutually affected*) and the absence of sensory symptoms.

Course. Usually 3 or 4 years to a fatal termination which ensues when laryngeal paralysis permits pulmonary disease.

Amyotrophic Lateral Sclerosis.

(*Charcot's Disease*). This disease, which occurs oftener in women than in men and usually between ages 35 and 50, is not caused by infectious disease or poisoning, but is believed due to an inherently deficient vitality. Cold, trauma, and shock seem to excite its onset in some cases.

The typical case combines the symptom-pictures of spastic spinal paralysis, bulbar palsy, and anterior poliomyelitis. It begins as a rule with symptoms of bulbar impairment but the arms or legs instead may be first affected. The first noticeable symptom is often a difficulty in swallowing and speaking. The lips or cheeks may feel stiff and there may be spasm of the tongue. Then the

legs and arms become progressively weak and stiff; they atrophy and become rigidly spastic, producing characteristic deformities. The patient may be confined to bed within a year because of muscular contractures in arms and legs. The reflexes are exaggerated; there is ankle clonus and a marked jaw-jerk. There may be slight pain but anesthesia and sphincter involvement, if they appear at all, wait until late in the disease.

There is degeneration of the ventral horn nuclei which also involves the terminals of the pyramidal tract fibres, hence the seemingly contradictory picture of spasticity, exaggerated reflexes, and marked atrophy. In time, however, the lower neuron symptoms will predominate and the spasticity and the reflexes may disappear entirely owing to the progress of the disease cutting off transmission entirely through the lower neurons.

Prognosis. Always grave. Duration, usually 2 to 3 years.

DIFFUSE DISEASE OF CORD

Myelitis.

Inflammation of the spinal cord may be acute, subacute, or chronic. When both white and gray matter are affected throughout an extensive area, or generally throughout the vertical extent of the cord, the condition is called **diffuse myelitis;** when both white and gray are involved for a limited vertical extent but including a complete cross-section area, it is called **transverse myelitis. Marginal** or **annular myelitis** affects the periphery alone. When the inflammation surrounds the central canal it is called **peri-ependymal myelitis** and when scattered in separated patches it is known as **disseminated myelitis.**

Acute Transverse Myelitis. Usually an acute softening of a section of the cord followed by inflammation; its extent is commonly 1 or 2 inches, affecting both gray and white matter. Exciting causes are injury, syphilis, muscular strains, exposure, alcoholism, and extension of neighboring inflammations. Predisposing factors are a neuropathic tendency, repeated exposures and muscular strains. It occurs most commonly in young adult males.

The extent of the paralysis will depend upon the location of the lesion. If the cervical cord is involved quadruplegia will develop; if below the cervical region, paraplegia (*usual*). At first there is a heavy, numb, weak feeling in the legs, with some pain in the

back. There may be spasmodic twitching of the limbs or even a general convulsion. Sometimes a chill precedes these symptoms, more often not.

Walking becomes difficult and in a day or two paraplegia develops, with some anesthesia. The sphincters are disturbed and there is retention or incontinence of urine, and constipation. Fever may or may not be present. There is often a girdle sensation at the level of the lesion.

If the lesion is above the lumbo-sacral region the paralysis is of the spastic type except for a zone of flaccid, atrophic paralysis at the level of the lesion. There will be anesthesia to touch, pain, and temperature in varying degrees as high as the lower limit of the lesion and a band of hyperesthesia marking the level of the lesion. When the anesthesia is incomplete that for touch will be most marked, and pain least.

When the lesion is in the lumbar region sexual power will be abolished, while if the lesion is cervical or thoracic there may be marked priapism without the patient's knowledge. Lumbo-sacral lesion may give rise to a flaccid paralysis with difficulty distinguished from anterior poliomyelitis, except by the absence of sensory and sphincter involvement in the latter.

Temperature of the limbs is at first slightly high but later subnormal. A sustained body temperature of 102° to 104° is a bad sign. Bedsores may appear early from trophic disturbance.

If the lesion is cervical the arms will be more affected than the legs and if the lesion is complete the intercostal muscles and presently the heart may be affected.

In non-fatal cases the disease reaches its height in a few days to 2 weeks, remains stationary for some weeks, and then gradually improves.

Differential Diagnosis. From spinal hemorrhage by the sudden onset of the latter and absence of fever. From multiple neuritis by the slower onset of neuritis and the more severe pain, local tenderness and sensory disturbances. Sphincter involvement is rare in neuritis. In hysterical paraplegia there are various stigmata of hysteria, no atrophy, and little spasm or rigidity. Acute ascending paralysis is progressive and usually without sensory disturbances or atrophy.

Subacute Myelitis is identical with acute except that the onset lasts from 2 to 6 weeks.

Chronic Myelitis. This is a later stage of acute myelitis, softening, injury, or hemorrhage. Is usually transverse but may be disseminated or diffuse. Commonest in early and middle adult life.

In chronic primary myelitis the legs feel heavy and tire easily; there is prickling and numbness in the feet; the waist may feel constricted. The reflexes are exaggerated, the legs stiffen, but atrophy is slight. Retention of urine and constipation occur. After a few months the symptom picture is one of partial paraplegia with exaggerated reflexes, rigidity of the legs, anesthesia, and sometimes slight pain in the back. There is some muscular atrophy. Retention of urine is marked. The gait is stiff and shuffling.

After a time the paralysis becomes more complete and the patient is bedridden with marked rigidity and contractures and more atrophy. Cystitis and nephritis may develop.

Chronic secondary myelitis presents the same symptoms as the primary form and is more common. **Compression myelitis** follows compression of the cord from tumor, aneurism, or vertebral caries. Early symptoms are usually irritation symptoms and the development of spastic paraplegia follows a period of weakness, spasms, and contractures.

Differential diagnosis is from tabes dorsalis, pachymeningitis, spinal tumors, multiple sclerosis, cerebral palsies, amyotrophic lateral sclerosis, and progressive muscular atrophy. In tabes dorsalis there are ataxia and sensory disturbances with little or no paralysis. In pachymeningitis there is history of injury, usually cervical, pain and anesthesia are marked, and the sphincters commonly escape. Spinal tumor develops slowly, the symptoms are more localized, and the pain and irritation symptoms are more marked. Multiple sclerosis shows speech disturbances, eye symptoms, and tremor. Cerebral palsies are unilateral in distribution and are without pain or vesical and rectal symptoms. Progressive muscular atrophy shows more atrophy and no sensory or sphincter involvement; usually begins in the hands.

Spina Bifida.

The diagnosis is easy and plain. Congenital absence of some of the vertebral arches permits a hernial protrusion of some of

the contents of the neural canal. May be (a) **meningo-myelocele,** cord and membranes both protruding, (b) **meningocele,** membrane and fluid in the sac, or (c) **syringo-myelocele,** the fluid being in the central canal and the lining of the sac formed by thinned-out cord and membranes.

Occurs in 1 child out of 1200, usually in lumbar or sacral region because these are the last to ossify. Two or three vertebrae are usually defective. The skin over the sac is brawny and indurated. The subjects are badly nourished and often mentally underdeveloped. Paraplegia is a common effect. Prognosis, usually fatal. A few cases survive to eighteen or twenty years; these usually have the membranes alone in the tumor.

Spinal Meningeal Hemmorrhage.

Hematorrachis, usually outside the dura mater, is the commonest form of spinal hemorrhage. Occurs in the newborn and in men oftener than in women. Injuries and severe convulsions are the commonest exciting causes. More rarely the rupture of an aortic or vertebral aneurism or an acute infectious fever is responsible.

A slight hemorrhage may occur unnoticed. A larger hemorrhage causes sudden severe pain in back and limbs, corresponding to the site of the lesion, and numbness, tingling, hyperesthesia, and muscular spasms, especially of the back muscles. Presently weakness or paralysis, sphincter disturbances, and anesthesia may develop. The case reaches its height in a few hours, followed by slow recovery or chronic meningitis.

The direct diagnosis depends upon history of injury or childbirth, sudden onset, and irritation symptoms quickly subsiding. If the patient lives 3 or 4 days the prognosis is good for ultimate recovery.

Hemorrhage into the Substance of the Cord (*Hematomyelia*).

May follow myelitis or tumors, or occur in connection with purpura hemorrhagica or vascular disease. Vascular syphilis, senile arteries, convulsions, old age, overexertion, exposure, injuries, are causes.

The onset is rapid. For an hour or two there may be numbness and weakness, followed by a sudden paraplegia with ataxia

or anesthesia, perhaps both. At first the reflexes may be absent (*shock effect*) but they will return and be exaggerated. Much pain in the back is felt. In about 10 days the symptoms diminish and the condition becomes one of chronic myelitis. In the more severe cases acute myelitis and death follow the hemorrhage. The lower the location of the hemorrhage in the cord the better the prognosis as to life.

Caisson Disease

(*Diver's Paralysis*).

A condition brought about by sudden changes in atmospheric pressure and characterized by paraplegia, muscular and joint pains, epigastric pain and vomiting. In the severer cases apoplectiform attacks occur, followed by coma and death. In milder cases complete recovery may occur in a few weeks.

Divers and others submitted to high air pressure may develop this condition within a short time after emerging abruptly into normal air pressure. While able to accommodate itself without danger to the change from low pressure to high, the body seems unable to endure the reverse transition unless it be gradual. In engineering practice it is now customary to bring workmen back from high to normal air pressure by successive and bearable stages.

The pathology is obscure but multiple minute hemorrhages in the spinal cord are sometimes found There is a theory that multiple emboli of nitrogen bubbles are formed when the pressure is lowered.

Tumors of Spinal Cord.

Uncommon. Lipoma may be congenital. Tubercle usually appears between ages 15 and 35.

The symptoms depend entirely upon the situation, character, size, and growth-rate of the tumor. In the early stages there are irritation symptoms, especially pain which comes early and persists. It is usually a "radicular pain" and is referred to the trunk or termination of the sensory nerve which enters at the site of the tumor, and is therefore deceptive. Girdle sensations, paresthesias, hyperesthesia, and finally anesthesia may follow, the location of the anesthetic belt marking the site of the tumor. There are likely to be spasms, contractures, and exaggerated reflexes on one side, or part of one side, especially one leg.

The size of the growth determines the extent of compression of the cord and consequently the range of symptoms. While the symptoms are usually unilateral they may become bilateral with enlargement of the tumor and ultimately lead to sphincter involvement, atrophy, bedsores, and death from exhaustion.

The Brown-Sequard Syndrome.

This is a name applied to the group of symptoms which follows a typical lesion involving one lateral half of the cord for a limited vertical extent, as a tumor. There is hemiparaplegia, with paralysis of muscle and tendon sense on the side of the lesion and cutaneous anesthesia, especially of pain and temperature, on the opposite side below the level of the lesion. The paralyzed side is frequently hyperesthetic and there exists a limited band or zone of anesthesia and flaccid paralysis at the level of the lesion.

Diagnosis. From caries of the vertebrae spinal tumor may be differentiated by the absence of kyphosis or tubercular history. Myelitis differs in its onset and developement. Pachymeningitis may not be distinguishable from spinal tumor. Spinal tumor in middle life is probably sarcoma or glioma. Syphiloma may be inferred if tumor symptoms develop in a case with a syphilitic history or with other recognizable syphilitic lesions.

DISEASE OF CENTRAL GRAY SUBSTANCE

Syringomyelia.

A rare disease characterized by development of gliomatous tissue in the central part of the cord, surrounding the central canal and forming cavities in the gray substance. Develops between ages 15 and 25, in men oftener than in women. Trauma, infectious diseases, and pregnancy seem to predispose.

The onset is gradual with aching pains in the neck and arms, paresthesis, and a wasting in the muscles of both hands which progresses upward toward the trunk. Pain and temperature sensations in the hands are lost but not touch. Later in the disease the legs become involved and a spastic paraplegia may occur. There is often a thoraco-lumbar scoliosis.

Vaso-motor, trophic, and secretory symptoms stand out plainly, owing to the location of their controlling cells deep in the gray matter. The more marginally placed motor cell groups suffer less.

Sweating or dryness of the skin, red, congested, œdematous hands, cutaneous eruption, erosions and ulcerations of the terminal phalanges, dry, brittle nails, and arthropathies or spontaneous fractures occur. Ultimately the bladder, rectum, and genitals are affected through their nerve centers.

The cardinal symptoms are its onset during or right after adolescence, the combination of progressive muscular atrophy with the peculiar dissociated sensory disturbances, the scoliosis, and the trophic abnormalities.

POSTERIOR COLUMN GROUP

Locomotor Ataxia.

(*Tabes Dorsalis, Posterior Spinal Sclerosis*).

This is a chronic, progressive disease in which the posterior roots and posterior columns are involved. A fibrosis occurs, an hypertrophy of the supporting elements of roots and cord with subsequent contraction and hardening which crushes the neurons. The symptoms arise from the progressive encroachment upon the sensory neurons, especially those conveying the muscular and tendinous sense through the posterior columns.

There is a common form, a paralytic form, and a neuralgic. It may be combined with other scleroses or with muscular atrophy.

Etiology. Heredity is unimportant. Chief factors are overstrain, exposure, excessive sexual intercourse, railroad travelling, toxins. Any factor which persistently jars the spinal cord, or which exhausts the nervous system may contribute. Excessive smoking, prolonged and profound emotion, acute infectious diseases, difficult labor with hemorrhage, may play their part. Syphilis is said to be the commonest cause and this fact has led many examiners into the error of assuming that locomotor ataxia is evidence of syphilis, *per se*.

Locomotor ataxia may be described in three stanges, the **pre-ataxic,** the **ataxic,** and the **paralytic.** These blend gradually into each other; there are no distinct dividing lines, just as there is no specific time limit for any stage. A case may remain permanently in the first or the second stage.

The **initial,** or pre-ataxic stage may last for a few months or several years. There is slight uncertainty in walking, especially in the dark, occasional darting pains in the legs and rectum, sensa-

tions of numbness in the feet (*walking barefoot on velvet*), and sometimes attacks of double vision and vertigo. Vesical control is weakened and sexual power impaired. The knee-jerk disappears early. The patient is profoundly fatigued without exertion.

The **ataxic** stage develops gradually and lasts for several years. Unsteadiness in walking increases, so that the patient begins to use a cane and has to watch his feet. The Romberg symptom appears; that is, the patient cannot stand with eyes closed without falling. Numbness in the feet increases and there are anesthetic spots on the feet and toes. Lightning-like leg pains occur and sometimes girdle sensation and attacks of epigastric pain with vomiting (*gastric crises*).

The pupils become small and react to accommodation but not to light (*Argyll-Robertson pupil*). Eventually the arms may develop the pain, anesthesia, and ataxia.

The Paralytic Stage. The muscular power of the legs remains fairly good but the ability to walk is entirely lost as the posterior spinal sclerosis more completely shuts off all afferent stimuli from muscles and tendons. Pains, although present, become less severe. The ataxia has extended to the arms but is not so marked there as in the legs. Vision is decidedly impaired. The bladder is paretic and requires the use of the catheter. There is, as a rule, no mental involvement.

Discussion of Symptoms. Owing to differences in the location and rapidity of developement of the sclerotic process, wide variations are found in the clinical pictures presented by different cases, yet the diagnosis is not difficult owing to the frequency of certain cardinal symptoms. A combination of early ataxia, Romberg symptom, Argyll-Robertson pupil, lightning pains, and absent knee jerk is sufficient for positive diagnosis. Of these, the pupillary changes may be last to develop.

The pains, of a lightning or lancinating character, appear oftenest in the legs in small areas or along the course of a nerve. They are so sudden and violent as often to cause a jerk of the limb. There is no regularity about them, either as to location or time; they may persist along one nerve for hours or shift entirely to the opposite limb without warning, and they may occur at intervals of a few minutes for several hours or only once or twice a month. They may disappear for several months only to return, but are usually present throughout the disease.

Limited areas of tactile anesthesia may appear early on the chest; the anesthesia in feet and legs progresses to include the thighs, arms, and lastly the trunk. It is greatest to pain but also involves the touch and temperature senses.

In 10% of cases optic atrophy appears in the pre-ataxic stage. If the patient escapes it until the second stage he may escape altogether. The left eye is more often affected. When atrophy occurs blindness usually develops in about 3 years. There may be ptosis or strabismus.

Arthropathies and spontaneous bone fractures are fairly common. The fractures, due to slight fall or injury or even to violent muscular contractions, heal readily and are almost painless. Trophic disturbances of the skin are common and a perforating ulcer may form on the foot, due to the loss of the trophic influence of the afferent nerves.

So-called "crises" of various kinds occur. Commonest is the "gastric crisis" with 2 or 3 days of severe vomiting, epigastric pain and diarrhea. Laryngeal crises are sudden spasms of the adductors or paralysis of abductors with dyspnea, cough, and croupy respiration. They are distressing but not dangerous. A cardiac crisis may bring an abrupt dyspnea with rapid heart action and a sense of suffocation.

Course. The disease is usually, but not always, progressive. Its duration varies from 1 to 30 years. The first and second stages may last between 5 and 20 years each. It may reach a certain stage and remain stationary for long periods. Death rarely occurs from locomotor ataxia or any of its crises. In the first stage the disease may be arrested and a complete cure affected. In the second stage a cure is exceedingly difficult but much improvement may be made.

Hereditary Spinal Ataxia.

(*Friedrich's Ataxia*).

There seems to be in some cases a hereditary lack of development of the cord, especially of the posterior columns and pyramidal tracts. The disease known as Friedrich's ataxia usually develops in children under 15, most commonly during the 12th year. Infectious fevers often initiate it.

It begins with ataxia and weakness in the legs which increases and after 5 or 6 years extends to the arms. Walking is seriously

impaired; the knee jerks are early abolished. There are no vesical or rectal symptoms but bulbar symptoms, especially thick, scanning speech and nystagmus may be present. Club-foot and lateral spinal curvature may appear. Ultimately paraplegia with contractures and atrophy begins.

The disease tends to progress but may have long stationary periods. It commonly lasts between 15 and 20 years.

Ventro-Lateral Column Group.

Two varieties of **spastic spinal paralysis** (*Lateral Spinal Sclerosis*) will be briefly described; they are **Little's Disease** and **Erb's syphilitic palsy.**

Little's Disease

Is a congenital spastic spinal paralysis due to developmental defects in the pyramidal tracts. It shows itself usually within the first year of life but may, in family types, be delayed as late as the fifth year. The child learns to walk "cross-legged", the spasticity of the leg muscles affecting the flexors more than the extensors. There are no mental symptoms, cranial nerve palsies, epilepsy, or hydrocephalus and by these absences the condition differs from ordinary cerebral diplegia or "birth palsy." The facial and throat muscles may be spastic. There is no pain.

Most cases grow worse instead of better and contractures finally render the patient helpless.

Syphilitic Spastic Spinal Paralysis.

Develops between 20 and 40 years of age, within 5 years after the initial lesion of syphilis. Onset gradual. It is a sclerotic process in the lateral columns.

It begins with a gradual stiffening of the legs, with cramps, muscular twitching, tremor, exaggerated knee-jerk, and ankle clonus. The Babinski reflex appears early. The gait becomes dragging, shuffling, and cross-legged. The thigh and leg are first affected, then the hip. Ultimately the patient may be confined to bed with contractures. Disuse atrophy of the muscles follows. There are rectal and bladder disturbances which distinguish this condition from Little's disease and other spastic paraplegias. It is chronic, lasting many years, and tends to be progressive. May be arrested or greatly relieved by treatment in some cases.

POSTERIOR AND LATERAL COLUMN GROUP

There are certain forms of degenerative sclerosis in which both the posterior and lateral columns are affected. Usually the lateral columns are first involved and then the posterior. Dana holds that there are three forms of combined scleroses which have clinical interest; they are

(1) Combined scleroses of profoundly anaemic and cachetic or toxic states. (*Putnam's type*).

(2) Hereditary spinal ataxia (*Friedrich's*).

(3) Hereditary ataxic paraplegia.

Putnam's type occurs most often in women between 45 and 65. Neuropathic diathesis predisposes. Exciting causes are malarial toxaemia, pernicious anaemia, suprarenal disease, and sometimes lead-poisoning.

The initial symptom is usually numbness in the extremities followed by weakness and finally paraplegia. The patient is anaemic and emaciated. Spasticity, exaggerated reflexes, ankle clonus, and perhaps ataxia and some anesthesia mark the paraplegia. Girdle sensations are uncommon and ocular and speech defects do not occur. Obstinate diarrhea is often present. Mental symptoms appear late. The prognosis is not good.

Hereditary ataxic paraplegia occurs in girls between 12 and 16 according to Dana. Neurotic heredity predisposes and no other etiology is known. Weakness and stiffness in the legs appear with marked ataxia which sometimes exhibits cerebellar characteristics rather than spinal. Reflexes are exaggerated and there is ankle clonus. There is no pain or anesthesia. The legs are chiefly involved but the arms may share the paralysis. The face and the sphincters escape. The general health, aside from the symptoms mentioned, may be quite good.

The diagnosis depends upon the age of onset, the slow and gradual progress, the family history and neuropathic diathesis, and the combination of ataxia and paraplegia. The course of the disease is long and slow and it is almost never fatal in itself.

MENINGITIS

A. SPINAL MENINGITIS

External Meningitis.

(*Pachymeningitis externa*).

A rare inflammation of the outer surface of the dura mater, always secondary to spinal caries, tuberculosis, psoas abscess, peritonitis, pyaemia, or purulent pleurisy.

Symptoms. Local pain in back, radiating pains, tenderness, hyperesthesia, paresis, paraplegia, exaggeration of reflexes, sphincter involvement and sometimes anesthesia.

The diagnosis depends upon the association of the motor and sensory symptoms with local pain and tenderness and the causative disease. The prognosis is generally unfavorable.

Internal Spinal Meningitis.

(*Pachymeningitis interna*).

Two types, the hemorrhagic and the hypertrophic, affect the inner surface of the dura mater. Excited by alcoholism, syphilis, exposure, and especially by trauma.

The symptoms are pain, shooting to occiput and back, stiffness in the neck with numbness, pricking, pain, and perhaps cramp and stiffness in the arms. There may be nausea and vomiting. In from four to six months paralysis begins in the arms with weakness, atrophy, rigidity, and contractures. There may be trophic changes, anesthesia, and hyperesthesia. Paraplegia, of the spastic type, follows. The patient finally dies from exhaustion. This disease must be differentiated from spinal tumor, Pott's disease, myelitis, torticollis, and progressive muscular atrophy. The cardinal points are: history of injury, slow, progressive course, bilaterality, and pain. The prognosis is generally unfavorable, though some cases are cured and others held stationary for long periods.

Acute Spinal Leptomeningitis.

Inflammation of the spinal pia mater is usually associated with cerebral leptomeningitis, seldom occurs alone. Children are more often attacked than adults, and men more often than women. It is always secondary to some infection, with or without trauma. Alcoholism predisposes. May be excited by surgical operation, typhoid fever, sunstroke, syphilis, or tuberculosis.

The symptoms develop with possible fever and chill and pain in the back and along the nerve trunks. The pain increases and the thoracic region becomes very tender and rigid. Opisthotonus may develop. The skin is hyperesthetic. There is constipation and sometimes retention of urine. The reflexes are at first exaggerated. Paralysis presently develops. Muscular atrophy and anesthesia may follow. The weakness increases, bedsores develop and death may occur from exhaustion. In tubercular cases the symptoms progress more slowly, in the septic form more rapidly.

Must be differentiated from tetanus by the absence of fever and traumatic history which would point to tetanus; from strychnine poisoning; from myelitis, which has less pain and more paralysis; and from gonorrhoeal rheumatism.

Prognosis. The acute form may subside into a chronic state. High fever, severe pains, and early paralysis are bad signs. Tuberculous meningitis rarely recovers.

A Chronic Spinal Leptomeningitis and Meningo-Myelitis.

Is described by Butler as secondary to cerebro-spinal meningitis, syphilis, or chronic alcoholism. Rare.

B. CEREBRAL MENINGITIS

Serous Meningitis.

(*Alcoholic Meningitis, "Wet Brain"*).

This is quite as much a toxaemia of the brain as a meningitis. Occurs mostly in males, especially after years of hard drinking, usually between ages 30 and 40. The use of chloral, cocaine, or morphine may cause it. Usually excited by a protracted drinking spell ending in delirium tremens.

Patient sinks into a semicoma after delirium tremens, with muttering delirium, delusions, and hallucinations. There is rapid pulse and normal temperature, or but slight fever. The pupils are small, the skin hyperesthetic. The stupor develops until in a few days it is difficult to arouse the patient at all. Stiffness appears in the arms, legs, and neck, and the latter is painful if moved. Cervical retraction may occur. The reflexes are exaggerated. The tongue is dry and coated. There may be involuntary bowel and bladder movements. The coma deepens and fever may rise to 104°. Pneumonia may occur and terminate fatally. Some cases improve before the final stage is reached and without high fever. The prog-

nosis is always bad after marked neck rigidity appears, better if the neck is not very stiff. The alcoholic history usually decides the diagnosis as against other forms of meningitis with similar symptoms.

Inflammation of the Dura Mater.

Inflammation of the Dura Mater of the brain is due to injury, mastoid disease producing caries of the petrous bone, necrosis, syphilis, or erysipelas. Symptoms are fever, headache, delirium, and sometimes convulsions and coma, and paralysis. The diagnosis depends upon the finding of a local cause.

Inflammation of the Pia Mater.

(*Leptomeningitis*).

Acute simple leptomeningitis occurs most frequently in young males. Trauma and acute alcoholism predispose. There is always an infection which has reached the membranes through the blood or through some neighboring disease area such as mastoid or middle ear disease. Head operations (*sinus operations*); disease, injury, or fracture of a cranial bone; pneumonia, septicaemia, pyaemia, scarlet fever, variola, rheumatism, empyema, typhoid fever, mumps, measles, endocarditis, or brain abscess may be the immediate cause.

Symptoms. Languor, malaise, headache, irritability, vertigo, and vomiting may appear as prodromal symptoms. The irritative stage then sets in with extreme headache, delirium, rigidity of the neck, cutaneous hyperesthesia, vomiting, retraction of the abdomen, irregular fever, contracted and often unequal pupils, and some times optic neuritis or retinitis. There is an early muttering delirium, perhaps with alternating stupor and violence. The headache is the most aggravated symptom. When there is vomiting it indicates its cerebral origin by its explosive, projectile character. The neck becomes extremely rigid and cervical retraction is marked; a general rigidity may develop. When the skin is scratched, a red line, the "tache cerebrale", appears. There is photophobia, sometimes ptosis or strabismus. The respiration is rapid and uneven, the pulse arrhythmic, and the fever irregular (*101° to 103°*) with constipation and oliguria, sometimes albuminuria.

In the final, or paralytic stage, there is stupor or coma. The pupils dilate, the skin becomes moist, and the muscular rigidity abates except perhaps for the abdomen. Urine and stools may pass involuntarily. Death usually occurs within a day or two after

this stage appears. The usual duration of the case is from 1 to 2 weeks but the patient may pass into a coma and die within 1 or 2 days. The prognosis is worse than in cerebro-spinal meningitis, not so bad as in tuberculous meningitis.

Acute Tuberculous Meningitis.

This is a localized manifestation of a general miliary tuberculosis, but even though secondary to tuberculosis elsewhere may be so severe as to to constitute practically the entire disease.

Symptoms. The onset is abrupt with loss of appetite, flesh, and strength, and marked irritability. The patient is usually a child and the occasion convalescence from some acute illness such as measles or pertussis, or a fall. In some cases the onset is so rapid that convulsions, coma, or delirium appear at once and without real warning. Usually, however, there is an irritative stage with headache, nausea and vomiting, chills and fever. There is marked photophobia and hyperacusis and the child cries or screams almost continuously. The pulse, at first rapid, becomes slow and irregular; constipation is the rule. Sleep is restless and disturbed; muscular twitchings are common; hyperesthesia usual. The pupils are contracted and cervical retraction usually occurs. During the first stage the fever may run 102° to 103°.

Gradually the symptom picture shifts into that of the pressure or paralytic stage. Dullness and apathy take the place of activity. The vomiting usually diminishes though it may persist. Constipation is obstinate and scaphoid abdomen appears. The pupils are now unequal or dilated; the respiration sighing or irregular; the pulse slow and intermittent. "Tache cerebrale" can be produced. Convulsions, nystagmus, strabismus, ptosis or optic atrophy may occur. Some form of paralysis (*paraplegia, monoplegia*) and cervical retraction are common. Gradually a typhoid state supervenes, with dry tongue, diarrhea, rapid pulse, and involuntary voiding of urine and faeces. Cheyne-Stokes respiration is not uncommon. The eyes are partly open and the eyeballs rolled upward. The temperature varies widely. A sudden extreme rise to 106° or 107°, followed by a quick drop to subnormal presages a speedy end. The duration of the disease is from 4 to 6 weeks and it is probably always fatal. The diagnosis depends upon the knowledge of a pre-existing tubercular focus somewhere, otherwise it may be impossible to distinguish from other forms of meningitis.

Epidemic Cerebro-Spinal Meningitis.

This is a specific infectious disease, due to the diplococcus intracellularis meningitidis, which probably enters by the nasal passages. It may be sporadic but is usually epidemic; it is moderately contagious. Occurs mostly in children and young adults.

Symptoms. The ordinary form invades suddenly with violent headache, severe chill, fever (101° to 102°), vomiting, and pain in the back and limbs. There may be an initial convulsion. So far it is impossible to distinguish from some other acute infections. Soon the indicative symptoms begin to show themselves. The neck and back become stiff and painful, with cervical retraction or even opisthotonus. Photophobia, hyperacusis, and delirium may be followed in bad cases by stupor or coma. Strabismus, nystagmus, ptosis, pupillary irregularity, and facial spasm indicate the involvement of the cranial nerve roots. The joints may be swollen. Kernig's sign is commonly present; it consists in inability of the examiner to extend the leg of the patient on the thigh against the persistent involuntary flexion.

The fever is irregular and not characteristic. In severe cases it may rise to 105° to 108°, always a bad sign. The pulse is usually full and rapid but may be abnormally slow. The respiration is not rapid unless there is pneumonia, but may take on a sighing or Cheyne-Stokes character. The bowels are constipated, the spleen swollen, and the urine may be albuminous and may even contain blood. Variable skin eruptions appear, petechiae and ecchymoses giving the condition the name "spotted fever" by which it is sometimes called.

The majority of deaths occur within 5 days. Cases which endure beyond that are likely to recover, though death may occur after several weeks or months.

Various forms of this disease are described, varying mostly according to severity. Thus a **mild** form presents the leading sypmtoms but in moderate degree and recovers easily. A **malignant** form is simply an aggravated and speedily fatal case. An **abortive** case is one which begins like an ordinary case but is surprisingly abated in two or three days, with quick recovery. Some cases are **intermittent.** A protracted case is called **chronic.**

Complications and Sequelae. More or less permanent impairment of cranial or other nerves often results from cerebro-spinal

meningitis. Optic neuritis and atrophy, deafness, or facial paralysis may ensue. Mental impairment is not uncommon. Nephritis sometimes follows. Pericarditis, pleurisy, and pneumonia are among the most serious complications and should always be watched for as they may be masked by the symptoms of the original disease.

Differential Diagnosis. Typhoid fever may develop meningeal symptoms. When pneumonia and meningitis coexist there may be some doubt as to which is primary. Acute rheumatic fever may resemble meningitis because of the joint symptoms but the absence of cervical retraction and cranial nerve symptoms in rheumatic fever should make the diagnosis easy. Acute tuberculous meningitis may be mistaken for this form unless the case history assists. Mortality from 20 to 75%, greatest in children under 5 years.

DISEASES OF BRAIN SUBSTANCE

Apoplexy from Intracranial Hemorrhage.

A hemorrhage may be dural or pachymeningeal, pial or subarachnoid, or central, or into the pons, medulla, or cerebellum. Of these the commonest is:

Central hemorrhage, due to rupture of the lenticulo-striate arteries, terminal branches of the middle cerebral, which supply the internal capsule, basal ganglia, and adjacent white matter. This occurs more frequently in males after 40. The tendency increases with advancing age, because hardened or senile arteries are most liable to rupture. Many conditions and diseases predispose, particularly those which lead to high blood pressure. Heart and arterial disease, nephritis, gout, rheumatism, alcoholism, infectious fevers, and syphilis are among the effective factors. The exciting cause is usually something which abruptly heightens the blood pressure, such as violent exertion, anger or excitement, excessive eating or drinking, straining at stool, or a cold bath.

Apoplexy occurs as a rule without prodromal symptoms, but in syphilitic cases it may be preceeded by vertigo, numbness of one hand or foot, loss of word memory, and a feeling of fullness or pain in the head. There may be nosebleed and irregular heart action. The attack is sudden, with or without coma.

A sudden vertigo is usually followed by immediate unconsciousness. So abrupt is the typical onset that it is popularly called "a

stroke." Retention or incontinence of urine and faeces may occur. The temperature in severe cases may be subnormal during the first 12 hours. Usually the temperature on the paralyzed side exceeds the other by a degree or two. In rapidly fatal cases, the coma persists, Cheyne-Stokes respiration appears, temperature rises to 102° to 103° until it falls again shortly before death, hypostatic pneumonia appears and death ensues in from 2 to 4 days. Some fatal cases run a slower course of from 2 to 4 weeks; in them consciousness is partly regained and the patient is restless and mildly delirious.

Most cases are not fatal. Coma disappears within 5 or 6 hours, leaving the patient weak and mentally confused, perhaps with speech disturbance. The paralysis should have been recognized during the coma by the complete flaccidity of the paralyzed side (*shock effect*). Rigidity sets in early, as soon as the shock has subsided, for this is an upper neuron paralysis, spastic type. In distribution it is a hemiplegia with the arm and leg most affected, the face less so. The tongue deviates toward the affected side if protruded. The upper branch of the facial nerve escapes and the eyes can be closed. There may or may not be hemianesthesia on the affected side, according as the lesion does or does not extend far back in the internal capsule. There may be motor or sensory aphasia according to the site of the lesion. There is commonly a slight elevation of temperature which completely subsides by the 10th day. Continued rise of fever after the 5th or 6th day indicates more hemorrhage or an extending inflammation.

In about 4 weeks the fever and the irritation symptoms have disappeared and the disease enters upon a chronic state. The mind is clear, headache is gone, the sensory symptoms less marked then at first, and there is slight motion of the leg and arm. The rigidity, developing by the 2nd week may amount to contractures; the flexors dominate the extensors and as a consequence the arm is held in a characteristic position, upper arm close to the body, forearm semiflexed on arm, wrist flexed on forearm, and fingers semiflexed. The gait is stiff and dragging, the affected leg being swung outward and around in an arc at each step. The face muscles draw toward the affected side, giving the face an asymmetrical appearance. Muscular atrophy is absent, until a gradual and moderate disuse atrophy sets in.

The reflexes are abolished during the flaccid period but return with the establishment of the chronic state. The knee-jerk is ex-

aggerated, ankle clonus is present, the elbow and wrist jerks are marked.

In the affected limbs there may be tremor, cramps, athetoid, choreic, or spastic movements, various vasomotor abnormalities such as excessive sweating, mottling of the skin, and skin eruptions. The patient is irritable and emotional and attention and memory may be impaired. Hysteria or insanity may develop.

Meningeal Hemorrhage. Rupture of the middle meningeal artery, or vein, or their branches may invade the meninges. Usually follows injury to the head, such as obstetrical injury at birth, or alcoholism, or insanity. Within a few hours after the accident or rupture cerebral symptoms appear. Parital or complete hemiplegia develops on the side opposite to the lesion, with increased reflexes, spasticity, and irregular, spasmodic movements. The eyes usually look toward the paralyzed side. The history of the case suggests the meningeal location of the hemorrhage.

Pons Apoplexy. The paralysis is likely to be bilateral (*diplegia*), sudden in onset, with minutely contracted pupils. The facial or ocular muscles are likely to be involved and their paralysis may be either spastic (*supranuclear*) or flaccid (*infranuclear*) according to the precise site of the lesion and its extent. A small pontine hemorrhage may produce only a hemiplegia, in which case the facial paralysis, if flaccid, will be on the side opposite to the paralysis of arm and leg.

Cerebellar Apoplexy. May be preceded by headache for several days, or may invade with sudden coma, stertorous breathing, vomiting, and hemiplegia. The paralysis is on the same side as the lesion. Always fatal.

Differential Diagnosis. Apoplexy must be distinguished from the coma of uraemia, opium, alcohol, epilepsy, hysteria, and acute cerebral softening.

In uraemic coma there is often a history of convulsions and of nephritis; the breath may have an ammoniacal odor. The face may show a swollen pallor. In suspected cases an immediate urinalysis should be resorted to.

Opium coma shows a dusky, cyanotic face, slow respiration, the pupils unequal and contracted to pin-point size.

Alcoholic coma may be recognized by the alcoholic breath but if liquor has been administered as a restorative this sign is without

value. The sour, mawkish smell due to the effect of alcohol on mucous membranes may be more revealing. It may be possible to rouse the alcoholic. In alcoholic coma there is no evidence of paralysis, while in apoplexy, even during the coma, one side of the face may be smooth and limp and the cheek may flap with respiration.

In epileptic coma there is almost invariably history of an immediately preceding convulsion of characteristic type. There is no hemiplegia.

Hysterical coma may be recognized by the peculiar appearance of the face, easier to recognize than to describe. The pupils are equal and normal in size and the eyeballs are turned upward. The lids resist opening; the lips are drawn stiffly; the face is usually flushed but not cyanotic.

From acute cerebral softening it may be difficult to distinguish apoplexy, but the more gradual onset and the premonitory symptoms argue for softening. The initial convulsive movements and the development of a slighter hemiplegia with anesthesia also suggest softening, as does a history of syphilis.

Prognosis. Many victims of apoplecic hemiplegia recover almost completely from the first attack. There is a likelihood of a second attack within 5 years, from which a minority recover. Third attacks are usually fatal. Reduction of the blood pressure after the first attack renders a second much less probable. Under proper care, most subsequent attacks may be avoided.

Acute Cerebral Softening.

Due to embolism or thrombosis, the former more frequent in women, the latter in men. Embolism usually occurs between 20 and 50, thrombosis between 50 and 70. Infectious fevers, endocarditis, pregnacy, profound anemia, and surgical operations lead to embolism; fatty heart, and syphilitic, lead, or gouty arteritis to thrombosis.

In embolism the onset is sudden with convulsive twitchings, then hemiplegia, and temporary loss of consciousness. Fever may develop after a few days, indicating a progressive inflammation from the embolic infarct. The chronic stage resembles that of hemorrhage.

Thrombosis often presents prodromal symptoms, drowsiness, numbness in the head, transient aphasia, vertigo. Compared to

hemorrhage, the onset is slow, the hemiplegia taking some hours to complete, during which time the patient gradually sinks into coma.

The prognosis in thrombosis is, on the whole, better than in hemorrhage and the recovery more complete. The diagnosis depends on the history of syphilis, the gradual onset, and the premonitory symptoms. An unusually sudden thrombosis may not be distinguishable from hemorrhage.

Hemorrhagic Encephalitis.

Occurs oftenest in young females and frequently as a result of infection, such as cerebro-spinal meningitis, typhus, typhoid, influenza, and malignant endocarditis, may occur in the puerperal state or in sunstroke.

Onset sudden with severe headache and fever, perhaps 105°. Vomiting, vertigo, photophobia, and delirium are followed by coma. Rapid, weak pulse; shallow breathing; sphincter involvement. May be convulsions, hemiplegia, aphasia, hemiopia, mystagmus, and speech disturbances. Prognosis fair. Mild cases recover in 2 or 3 weeks; severe cases may die of exhaustion, but most recover.

Brain Abscess.

This is due to infection, of various types and modes of entrance. Suppurative processes in injuries, tumors, or infectious fevers may produce abscess of the cerebral substance or it may follow disease of the nose, ear, or cranial bones. Probably the commonest exciting cause is disease of the middle ear or mastoid portion of the temporal bone.

Acute cases. The onset is quite abrupt with pressure symptoms, toxic symptoms, and irritation symptoms. In the first group are persistent and severe headaches, vertigo, vomiting, and mental dullness or delirium, changing to coma. The temperature and pulse are usually normal or subnormal, but may vary. The pupils may be irregular and there may be optic neuritis. The toxic symptoms are anorexia, prostration, emaciation, irregular fever, and mental or sensory disturbance. The irritation (*or destruction*) symptoms are convulsive (*epileptiform*), aphasia, cranial-nerve disorders, and paralysis (*usually hemiplegia*). The final stage of cerebral abscess is a profound coma and death by exhaustion.

Chronic cases. Marked by slow onset and development. There may for years be depression, mental irritability, headache, vertigo,

and perhaps convulsions, without irritation or paralytic symptoms to point out the positive organic nature of the case. Occasionally there may be an exacerbation of the symptoms with severe attacks of vomiting, intense head pain, and perhaps delirium or convulsions; these may subside, leaving the patient feeling fairly well. Finally the symptom picture becomes similar to that of the acute form and the final, and fatal, stage of the disease is ushered in. In other cases a slow-moving symptom picture may suddenly be broken by violent convulsion, or complete coma and death occur speedily.

Brain abscesses occur most commonly between ages 10 and 30 but may range from 1 to 50. They affect the cerebrum oftenest, especially the frontal and temporal lobes and more commonly the right side; next the cerebellum, and are least frequent in pons and medulla. An acute brain abscess usually lasts from 5 to 14 days, rarely as long as a month; in chronic cases the latent period may last from a few weeks to 2 years, the terminal stage a few days.

The diagnosis may be made with reasonable certainty from the combination of delirium or coma, irritation symptoms, and normal subnormal, or irregular temperature with history of injury or of disease of cranial bones. The conditions of grave septic poisoning are mixed with abundant evidence of cerebral localization.

Chronic Hydrocephalus.

This usually begins at birth or within six months. Late childhood or adult cases (*rare*) are usually due to tumor or inflammation of the brain obstructing the cerebral aqueduct and the venae Galeni. Infantile cases may often be connected with a history of alcoholism, lead-poisoning, tuberculosis, or syphilis in the parents, or with rickets. Cervical trauma at birth, due to misuse of obstetrical forceps, and unrecognized at first, is a factor in many cases.

The child's head increases in size and develops a characteristic appearance. It is globular; the veins are visibly distended, the sutures remain open, and the anterior fontanel is large and bulging. The face is small and the eyelids can be raised only with difficulty. The head of a normal infant 1 year old should be about 18 inches in circumference. Any marked increase beyond this measurement should suggest hydrocephalus.

The child becomes irritable and restless and there is general impairment of nutrition although appetite may be good. Growth is subnormal and as a rule the mind does not develop normally, al-

though there are precocious hydrocephalics; the child seldom learns to walk. Strabismus is often present, optic atrophy sometimes. Within a few years, the fluid tension increasing, vomiting, coma, and convulsions set in and the child dies from exhaustion.

Hydrocephalus must be distinguished from rachitis by the shape of the head which in rickets is flattened at the vertex and looks oblong from above, and by the bone deformities which occur in rickets.

Infantile Cerebral Palsies.

May be due to diseases, injuries, or emotional disturbances profoundly affecting the mother during pregnacy or, more commonly, to intra-uterine injury or injury at birth. Forcible twisting of the infant neck may interfere with the cerebral blood supply. Some cases develop after birth, almost always within the first three years, usually ofter some acute infectious disease.

Symptoms. In about one-fourth of all cases it is initiated by a general convulsion and fever. The convulsion may persist for hours and the fever for several days. During or right after this acute stage paralysis appears, a hemiplegia or diplegia. The paralysis may gradually improve thereafter, the arm being last and least improved. Growth is retarded on the affected side so that the one leg may be finally one or two inches shorter than the other. the paralyzed limbs are cold and rigid, with contractures. Clubfoot is common. Motor spasms may develop and there is ankle clonus with exaggerated knee jerk.

In about one-fourth of all cases the intelligence is normal and the remainder are evenly divided between feeble-mindedness, imbecility, and complete idiocy. Cranial asymmetry and microcephalic or macrocephalic skull are common. There may be physical improvement after puberty. This condition must be distinguished from paralyses of spinal origin by the absence of rigidity and reflexes in the latter.

Tumors of the Brain.

Commonest are sarcoma, tubercle, gumma, and infectious granuloma. Occurs at all ages up to 50, one-third prior to age 20, commonest in males. In childhood tubercle is the most common form; after 20 years, gumma, glioma, and sarcoma; in middle and late years, sarcoma, gumma, and cancer.

Symptoms are persistent, intense headache with marked exacerbations; vomiting and general or local convulsions; vertigo; visual defects; and perhaps mental dullness. The vomiting is likely to be projectile in character and is followed by profound weakness and emaciation. Pain is intense. Paralysis, blindness, and other cranial nerve symptoms occur, depending upon the size and precise location of the tumor. The patient becomes bedridden and dies of exhaustion after 1 to 5 years.

Optic neuritis, recognizable by the "choked disk" is present in four-fifths of all cases and therefore, when associated with atrocious head pain and projectile vomiting, is almost pathognomonic of brain tumor. There may be general convulsions, apoplectiform attacks, and occasionally true apoplexy. There is nearly always mental impairment.

Aside from the general symptoms of brain tumor, each growth causes symptoms dependent upon its locality. Thus the occurrence of anarthria suggests bulbar tumor; aphasia, frontal tumor; extreme vertigo and early loss of equilibrium, cerebellar growth; deafness, temporal lobe involvement; athetoid movements, the optic thalamus. The precise localization is of minor importance unless surgery be contemplated, because the condition is not amenable to treatment and death usually occurs within 1 to 5 years; rarely a case may remain stationary for many years.

Multiple Sclerosis.

Patchy hardening within the substance of the central nerve system. Starts usually between ages of 20 and 30, more often in males, and seems to be excited more often by infection than by any other cause. Slow metallic poisoning, exposure to cold, shock, fright, and trauma are also causes. Malaria, typhoid fever, the exanthemata, pneumonia, rheumatism, pertussis, diphtheria, dysentery, cholera and erysipelas may lead to multiple sclerosis. Strong inoculations with serum or antitoxin may be a factor.

The onset is slow and gradual. There is rigidity and weakness in the legs which are perhaps numb; or tremor of the hands. Ataxia of the legs soon develops and walking becomes difficult. The hand tremor is now of the intentional variety. The speech becomes slow, scanning, and syllabic. There may be some dysphagia. The limbs atrophy. There is little pain, but limited areas of anesthesia may appear. The knee-jerks are exaggerated and there is ankle

clonus. The tremor becomes so jerky that the patient can dress himself only with the greatest difficulty. Nystagmus is often present.

There may be mental slowness, perhaps melancholia, or periods of uncontrollable laughing or crying.

The cardinal symptoms are: intention tremor, nystagmus; scanning speech; exaggerated knee-jerks; ankle clonus; ataxia; and attacks of vertigo and apoplectiform or epileptiform seizures. The disease must be differentiated from spastic spinal paralysis, tabes dorsalis, Friedrich's ataxia, bulbar paralysis, dementia paralytica, hysteria, and chronic meningitis. The prognosis is good as to life but doubtful as to recovery. Apparently recovered cases frequently revert after some years.

Syphilis of the Nervous System.

The diagnosis of this condition depends upon recognition of the existence of syphilis elsewhere in the body. It is otherwise impossible to be sure that the lesions causing nervous symptoms are syphilitic or of some other character. The symptoms depend largely upon the exact location of the gummata and are those of tumor, except that the effects may be irregular and transitory, with marked aggravation and improvement from time to time. The headache of syphilis is worse at night, very intense, and irregular as to locality, and may be periodical.

DISEASES OF THE PERIPHERAL NERVES

A. DISEASES OF SENSORY NEURONS

Neuralgia.

Neuralgia is a term applied to a condition in which pains occur in nerves, usually acute, lancinating, and recurrent, and usually unaccompanied by structural changes in the nerve itself. Any peripheral sensory nerve may be the seat of a neuralgia. Certain varieties are commonly recognized.

Coccygodynia.

Affects the lower posterior branches of the sacral nerves; it is nerve pain in the vicinity of the coccyx. It may result from spinal irritation or as a referred pain from pelvic disorders, or from partial disrelation of the bones entering into the sacroiliac joint. Usually defecation is painful.

Tarsalgia.

Policeman's disease is a neuralgia of the sole of the foot, commonly due to protracted standing, going barefoot, or other factors which produce flat feet and stretch the plantar ligaments.

Morton's Neuralgia.

Due to flattening of the anterior transverse arch of the foot, occurs most commonly in women and is caused by trauma or tight shoes.

Sciatica.

This is an irritation of the great sciatic nerve (*sciatic neuralgia*) which should be distinguished from a real inflammation of that nerve (*sciatic neuritis*). It occurs most frequently between the ages of 30 and 50, more commonly in men than in women. Among predisposing factors are occupations which include strain and exposure, a neurotic constitution, and the arthritic or gouty diathesis. There seems a subtle relationship, not clearly understood, between rheumatism, gout, arthritis, and sciatica. The exciting causes of sciatica are injury, exposure, pelvic disease, pressure from hard seats, etc. The condition may be closely counterfeited by irritation of the lower lumbar and sacral nerve trunks in disease of the vertebrae or of the spinal cord, or as a result of the pressure of pelvic tumors.

The onset of sciatica is usually sudden with acute pain in the back of the thigh, following the course of the nerve. The pain may extend from the vertebral column, beginning at the exit of the fourth and fifth lumbar nerves, or it may begin at the great sacrosciatic foramen and extend downward. It may run down into the leg and even into the foot. The pain is increased by motion and therefore the pelvis tilts upward on the sound side and the trunk leans over toward the affected side. The pain is of a dull character, almost continuous, with exacerbations of sharp, burning, lancinating pain of great intensity. There are special tender points at the sciatic foramen, in the middle of the back of the thigh, behind the knee, in the middle of the calf, behind the external malleolus, and at the back of the foot. In rare cases there is anesthesia along the course of the nerve; more commonly there is a sensation of numbness and tingling and the affected limb may feel heavy and cold.

Sciatica usually lasts 2 to 3 months, but may recover in a few days or endure for 6 months. It must be distinguished from or-

ganic disease of the cord or vertebrae, hip-joint disease, and the pain due to the pressure of tumors. A direct diagnostic sign of sciatica is the fact that if the thigh is flexed upon the abdomen and the leg extended on the thigh a sharp pain is felt at the sciatic foramen.

Lumbo-Abdominal Neuralgia.

Affects the upper lumbar nerves and their parietal branches. True neuralgias in this region are infrequent, most pains in these nerves being referred from abdominal disease, hip disease, or disorders of the internal genitals.

The chief symptom is pain in the back extending to the genitals or hypogastrium of one side, or down over the buttock. With careful palpation the tender nerve may be followed from its spinal exit to its termination. **Femoral neuralgia** is that in which the pain is limited to the branches of the femoral nerve in the anterior thigh.

In the absence of discoverable organic disease a unilateral pain of this character may be called neuralgia. Lumbago is limited to a single set of back muscles which are excessively painful on deep pressure. Lumbar neuralgia is most frequently due to an abnormality of relation between lumbar vertebrae and a consequent irritation at, or near, the point of exit of the sensitive nerve.

Mammary Neuralgia.

Mastodynia is due to injury, pendant breasts, anemia, and pressure from badly fitted corsets, the latter fortunately an uncommon cause today. It may occur during pregnacy, or lactation, or in hysterical girls and women. It should lead to local examination for possible tumor.

Herpes Zoster.

Shingles may be classed either as a neuralgia or as a trophoneurosis, since its nerve pains are accompanied by a peculiar vesicular eruption along the course of the affected nerve and due to the loss of the trophic influence of the bipolar nerve cells of the dorsal root ganglia, or one ganglion. Usually involves only a single spinal nerve which is most commonly a lower thoracic but may be any spinal nerve.

Due to hemorrhagic inflammation of the posterior root ganglion. Infections, wounds, rheumatism, syphilis, gout, or morphine poisoning may predispose or excite the attack.

The onset is gradual, first paresthesia along the course of a nerve, then pain, followed by the appearance of little vesicles. These in a few days become purulent and then slough, leaving little scooped-out ulcers. As one crop of vesicles develops a new one starts and there may be several stages present at the same time. Usually lasts several weeks and subsides gradually.

Intercostal Neuralgia.

Must be distinguished from pleurisy by the absence of fever in the former and also the absence of the physical signs of pleurisy. Intercostal neuralgia generally has a history of rheumatism, neurasthenia, hysteria, anaemia, heart disease, dyspepsia, lead-poisoning or malaria. The nerve can be traced from its exit from the spine to its termination by the succession of tender points elicited by palpation. Usually lasts a few weeks but may run into months.

Cervico-brachial Neuralgia.

Not frequent. May occur in gouty, rheumatic, or neurasthenic patients. It should be remembered that it may be symptomatic of tabes dorsalis or other cord disease, and that caries of the cervical vertebrae may give rise to root pains simulating a severe neuralgia.

Cervico-occipital Neuralgia.

Is commonly unilateral, affecting the neck and back of head. May result from eye-strain, brain tumor, meningitis, or rheumatism of the neck. Occurs in spinal irritation (*boring pain*), migraine, neurasthenia (*dull, tired ache*), and hysteria.

Trigeminal Neuralgia.

This is a very frequent neuralgia and occurs in several forms. **Tic douloureux** is that form which results from disease of the semilunar (*Gasserian*) ganglion. It is unilateral and may involve only one branch of the trigeminal, or all three. The chief symptoms are the paroxysms of intense, radiating pain, which dart into some part of the face, as the upper lip, teeth or eye. During the paroxysms the face is flushed and the nose runs. The expression of the face is one of great agony. Attacks may be excited by a cold draft or by the act of speaking or eating.

Most cases occur after middle life but there is no set rule. The condition is essentially chronic though there may be long periods

of intermission. Some cases are periodic, appearing only at certain times of the year.

Symptomatic trigeminal neuralgia is that which is referred irritation from disorders of the eye, nose, ethmoid antrum, teeth, or is due to rheumatism, syphilis, gout, diabetes, malaria, or trauma.

B. DISEASES OF MOTOR NEURONS

Multiple Neuritis.

Multiple Neuritis is a disease of acute onset but running a subacute or chronic course, and characterized by weakness or paralysis of all four extremities, accompanied by atrophy, pain, and tenderness. It is an inflammation of the peripheral nerve trunks. Occurs in epidemic form as beri-beri, an acute infection. The non-specific forms are a **motor** form, a **sensory** or pseudo-tabetic form, and an **acute pernicious** form.

The **motor** form is commonest. Occurs in early adult life, in women more often than in men and only occasionally in children. Among predisposing causes are tuberculosis, anaemia, exposure to cold and wet, excessive tea-drinking, and sexual abuse. The exciting causes include alcohol (*commonest*), poisoning by copper, lead, phosphorus, or arsenic, rheumatism, diabetes, and almost any infectious disease.

The onset is sudden, with fever for a day or two, and pains in the legs and feet, but may have been preceded by a week or two of slight pain and general weakness, especially in the legs. The initial pain and weakness increase and the arms may be affected but less than the legs; muscles and nerves are excessively tender. The skin may be red or slightly œdematous.

The weakness increases and in a week or so there will be paralysis, first of the anterior muscles of the legs and to a less extent in the extensors of the hands. Paralysis extends to nearly all forearm and leg muscles and these begin to atrophy. Pain continues intense. The motor cranial nerves are only occasionally affected. The condition now becomes a double paraplegia with wrist-drop and foot-drop. Knee-jerk is absent. There is tactile anesthesia with delay in pain and temperature conduction, with impairment of the muscular and tendinous sense. The sphincters escape involvement.

In cases of alcoholic origin there may be mental involvement, muttering delirium or onfusional insanity. In diphtheritic paral-

ysis the throat and eye muscles are involved and the extremities less so, and there are fewer sensory symptoms.

The **sensory** form most frequently follows diabetes or infectious or metallic poisoning. It is similar to the motor form except that the paralysis is less marked and the sensory symptoms exaggerated. Muscular and articular senses may be wholly lost and inco-ordination is one of the earliest and most pronounced symptoms.

The **acute pernicious** form seems to be septic. It invades with great rapidity and death usually ensues within a few weeks by involvement of the cardiac and respiratory nerves. Landry's paralysis is a related condition.

Differential diagnosis of multiple neuritis must be made from anterior poliomyelitic and myelitis. From the former it differs in the presence of pain, the early tenderness of nerve trunks, the history of the case, and the age of the patient. In myelitis the bladder is affected, the knee-jerks exaggerated, the atrophy of muscles is less, and the development more rapid. Cardinal symptoms of multiple neuritis are alcoholic history, acute onset, gradual paralysis of legs and hands, wrist-drop and foot-drop, severe pains and tenderness, absence of sphincter involvement, and loss of knee-jerk.

The prognosis is good except in cases of alcoholism or toxaemia. Complete recovery is the rule.

Paralysis of the Phrenic Nerve.

If bilateral, there is no movement of the diaphragm and the abdomen is drawn in. Dyspnea and rapid breathing follow the slightest exertion. If the diaphragmatic paralysis is the sole symptom the trunk of the nerve is affected rather than its spinal origin. Most commonly phrenic nerve paralysis is a consequence of surgical operation, fracture of cervical vertebrae, tabes dorsalis, Landry's paralysis, or disease of the cervical cord. It may ensue from the pressure of a mediastinal tumor, or accompany pleurisy, peritonitis, or hysteria.

Combined Brachial Paralysis.

Injuries to the shoulder, the pressure of a crutch, obstetrical injury to children, peripheral neuritis, and hysteria may cause a combined paralysis of several of the nerves entering into the forma-

tion of the brachial plexus. The exact distribution will vary, but the condition can be distinguished from spinal cord disease by the fact that there are sensory as well as motor symptoms and the area of distribution corresponds to that of several known peripheral nerve trunks. Muscles rather than movements are paralyzed.

There are, in varying degrees according to the extent of the lesion, paralysis, muscular atrophy, pain and tenderness, anesthesia, and perhaps trophic and secretory disturbances.

Single Brachial Plexus Nerve Paralysis.

Any nerve of the brachial plexus may be paralyzed by sudden neck strain or injury.

Posterior thoracic. Supplies the serratus magnus. Shoulder movements are impaired and there is difficulty in raising the arm above the horizontal position. When the arm is put forward the posterior edge of the scapula recedes from the thorax and the scapula is rotated, its lower angle moving inward and upward.

Circumflex. Supplies the deltoid, teres minor, third head of the triceps, and the shoulder joint. The arm cannot be outrotated or elevated. There is anesthesia and atrophy of the shoulder muscles.

Musculo-spiral (*Wrist-drop*). There is inability to extend the hand and fingers. There may be atrophy and is usually anesthesia. If due to pressure the course is usually short but if caused by lead-poisoning, neuritis, or injury to the nerve it may be long. Exclude progressive muscular atrophy and the prognosis is good.

Median. Rarely paralyzed alone. Abduction and flexion of the thumb and first and second fingers are affected. The grip is weakened. There is anesthesia and the thenar eminence may atrophy.

Ulnar. Frequently paralyzed alone. Usually escapes in lead-poisoning but is affected early in progressive muscular atrophy. The ring and little fingers are weak and the hand cannot be closed tightly. Claw-hand develops. There may be pain and tenderness, followed by anesthesia.

Lumbar Nerve Paralyses.

Usually due to psoas abscess, caries of the vertebrae, pelvic tumors or injuries, impacted faeces, hip-joint disease, obturator hernia, or the pressure of a foetal head.

If the two upper lumbar nerves are affected the symptoms are largely sensory. If the next two, there is difficulty in extending the leg and in flexing the thigh on the trunk. If the obturator nerve alone is paralyzed the thigh cannot be adducted or the leg crossed and outrotation of the thigh is impaired. If the posterior branches of the lumbar nerves are paralyzed there is weakness or paralysis of the erectors of the spine. This happens in progressive muscular atrophy.

Peripheral Leg Palsies.

May be single or combined, and due to dislocation, injury, hip disease, tumors, or neuritis. Hysteria may produce paralysis of any of these nerves. The foot cannot be moved or the thigh flexed. Rotation of the thigh is impaired. Pain, atrophy, anesthesia, and vasomotor disturbances develop. To be differentiated from spinal cord disease by its unilaterality and the absence of any sphincter involvement, which would almost certainly accompany disease of the sacral cord.

Peripheral Facial Palsy.

(*Bell's Palsy*).

This is the commonest variety. It involves the facial nerve (*not the nucleus*) usually after its emergence from the stylomastoid foramen. Due to infection, exposure or rheumatism. Occurs more frequently in males between the ages of 20 and 40. May follow injuries to the temporal bone or ear disease. A neuropathic constitution predisposes.

Its onset is sudden and the paralysis may be complete in a few hours. If it does not become complete, secondary contractures may appear within two or three months and the mouth will then be drawn toward the affected side.

In a complete Bell's palsy, one side of the face is paralyzed, the eye cannot be completely closed, the forehead cannot be wrinkled. The protruded tongue does not deviate from the middle line, as will be seen by noting its relation to the teeth, but will appear to deviate because of the drawing of the mouth to the sound side by the unopposed action of the unparalyzed muscles. There is atrophy, and the muscles are flaccid.

To be distinguished from facial paralysis of cerebral origin, in which the eye can be closed and the upper branch of the nerve is not much involved, and from nuclear palsy, which has a history of lead or diphtheritic poisoning or bulbar palsy. Prognosis good.

Pusedo-Hypertrophic Muscular Paralysis.

Usually occurs in children under 10 and in boys oftener than girls. The exciting cause is usually an injury or an acute disease but a neuropathic heridity predispose.

The first symptom observed is weakness of the legs, producing a waddling gait and a tendency to stumble and fall. Presently the leg muscles, especially the calf muscles, become hypertrophied. They have a hard, inelastic feeling. The hypertrophy may extend to the thigh and to the gluteal and lumbar muscles. Sometimes some of the muscles of the upper part of the body, particularly the infraspinatus, supraspinatus, and deltoid, may hypertrophy, but often they escape.

Coincident with the hypertrophy there is atrophy of muscles. While they increase in size due to an overgrowth of fibrous tissue the essential muscle tissue wastes and the patient presents the spectacle of large and apparently robust muscles ineffective.

The gait becomes more waddling; there is difficulty in climbing stairs. The patient cannot get up from the floor except by going forward on hands and knees, then rising to feet and hands, then bracing hand against knee, then the other hand against the other knee, to rise. This peculiar method of rising from the floor is almost pathognomonic of pseudo-hypertrophy.

Lordosis is marked when standing and there may be scoliosis. The knee-jerks gradually diminish and finally disappear. There is no pain, or other sensory disturbance and no evidence of organic spinal cord disease. The mind is normal.

This disease may last from 10 to 25 years and its progress is always slow. It is somewhat intractable and the prognosis eventually becomes grave; patients do not, as a rule, live long after becoming bedridden.

Other Muscular Atrophies.

Several varieties of muscular atrophy are described as affecting certain muscles or groups of muscles. These do not usually appear in typical forms. In general, any muscular atrophy not demonstrably due to lesion of the ventral horns of the cord or to peripheral nerve disease or injury may be considered as caused by an obscure disturbance of the trophic influence of the lower neurons over their dependent muscles.

THE NEUROSES
DISEASES OF UNKNOWN PATHOLOGY
A. SENSORI-MOTOR NEUROSES

Epilepsy.

The predisposing causes of epilepsy are: Injuries, at birth, heredity, alcoholism, syphilis, the intermarriage of neurotic persons, and powerful emotions during pregnancy. Among many exciting causes are: Rickets at the time of dentition, injuries to the head, fright, sunstroke, syphilis, alcoholism, masturbation, and infectious diseases, especially scarlet fever.

The precise pathology of epilepsy is unknown. The symptoms and the manner in which attacks are excited suggest an irritability of the superior cervical ganglion which causes it, under proper circumstances, to produce an abrupt congestion of the brain. Color is lent to this theory by the fact that surgical removal of that ganglion has resulted in the disappearance of epilepsy; the operation was abandoned because no patient survived it more than four years. It appears, then, that through some change in the superior cervical ganglion not yet discoverable upon examination, there is set a ready mechanism which, when excited, produces the epileptic seizure. It may be excited, or tripped, by many and various factors. Worms, dyspepsia, peripheral nerve lesions, ocular, auditory, and dental irritations, may be the exciting causes. As a rule, each case of epilepsy has some particular form of excitation which ordinarily initiates the attacks; this habitual excitant, however, may give place to another in the same case, and any unusual nerve irritation may effectively start a seizure in an epileptic subject.

Epilepsy is a chronic nervous disorder characterized by peculiar recurrent seizures of varying intensity, from the major attack (*grande mal*) which climaxes in a severe convulsion, and the minor attack (*petit mal*) in which there is a transitory loss of consciousness, down to the psychical form in which consciousness is not lost at all.

The former type is most frequent. Preceding the major attack the patient experiences, for a few hours or perhaps a day, a feeling of malaise, vertigo, or irritability. Immediately before the attack sensory disturbances may be felt, termed the **aura.** These consist of epigastric or abdominal distress, palpitation of the heart, mental

states of terror or perplexity; subjective sensations of taste, odor, sound, light, or color; or rapid moving or turning of the body.

Grande Mal.

Following the aura the patient enters the convulsion, usually with a loud cry. He falls unconscious and his muscles become rigid. The legs are extended, the hands tight shut, the jaw clenched, and the head turned forcibly to one side. The muscles of respiration are spastic and as a consequence of the interruption of breathing the face becomes reddened and then deeply cyanosed. Within about one minute the tonic convulsion gives way to a clonic. The extremities jerk rhythmically and with considerable vigor; the muscles of the face, jaw, eyes, and eyelids work convulsively. The head may beat upon the floor by contractions of the neck muscles. Foam appears around the mouth. In this stage the tongue may be bitten. The cyanosis lessens; the bladder and rectum may be emptied. In two or three minutes the convulsions cease and the patient subsides into a state of deep coma.

In the coma the breathing is stertorous and the patient is relaxed. The unconsciousness, at first profound, progressively lessens to a stupor. Consciousness returns in from a few minutes to an hour or more but a somnolent condition may last several hours. There may be a temporary paralysis from exhaustion, with loss of knee-jerk. Nystagmus sometimes appears. Transient albuminuria or glycosuria may be present. In some cases one attack follows another for several hours, the patient lacking time for recovery between seizures, and to this condition the term **status epilepticus** is applied.

In major epilepsy the frequency of attacks varies widely and in few cases is there any regular periodicity. A rare case may average six months between attacks; more commonly several days elapse; in extreme cases there may be one or more attacks every day.

Petit Mal.

The minor attack is less severe. The patient suddenly stops whatever he is doing and the face assumes a somewhat characteristic expression; the features are fixed, the face pale, the eyes are open and pupils dilated; there is a slight twitching of the muscles of the face or limbs and a momentary loss of consciousness. The attack is so brief, a few seconds, that the patient does not usually fall. He is unconscious of what has happened, taking up

his work or his speech just where he left it. Sometimes during the minor attack the patient takes a few steps or runs a short distance, confusedly.

Psychical Epilepsy.

The purely psychical form of epilepsy is uncommon. There may be sudden, automatic, violent movements, or periods of maniacal excitement following or replacing a minor attack. Crimes of violence may be committed in this state. Somnambulistic automatism may occur.

Continuance of any form of epilepsy, but especially that with major attacks, undermines the constitution. Children with epilepsy are likely to be undersized and to present some of the stigmata of deviation. Mental deterioration is common, though occasionally an epileptic may be a mathematical prodigy or show other marked ability. As a rule, the epileptic is irritable, selfish, mentally unstable, and a poor student. In perhaps 10% of cases insanity develops.

Differential Diagnosis. Epilepsy must be distinguished from other forms of convulsion, especially hysterical. Hysterical patients do not hurt themselves in falling, almost never bite the tongue, their movements are more co-ordinate, and the facial expression in the coma is one of hypocrisy. Cyanosis is never so marked in hysteria. Epileptiform seizures in children may be due to peripheral nerve irritation and may be correctible by surgical procedure, such as circumcision, etc.

Prognosis. The disease runs an essentially chronic course. A few cases recover spontaneously, but less than half can be cured by treatment of any or all kinds. Life is somewhat shortened by epilepsy but death rarely occurs as a direct result of the disease, or one of its attacks.

Migraine.

(*Hemicrania*).

Sometimes called "sick headache." By many, this is regarded as a constitutional disease. It begins at puberty or earlier, sometimes as early as the 2nd year, in girls oftener than in boys. There are many theories as to its cause. A neurotic family history certainly predisposes and rheumatism, gout, and epilepsy in the family seem to be factors. Autotoxaemia from intestinal poisons, errors

in refraction, overwork, shock, injury, and exhausting disease are sometimes blamed.

Auerbach has advanced an interesting and plausible theory. He holds that in most cases of hemicrania there is a congenital disproportion in size between the brain and the cranial vault which contains it; that this disproportion brings about an excessive intracranial pressure more particularly on the side on which the cerebrum is most developed (*left side in right-handed persons*); that any factor which temporarily engorges the brain with blood will result in painful pressure upon the afferent nerve ends in the dura mater; and that the characteristic headache and other symptoms of migraine result from the effect of this irritation upon the nerve centers.

This theory adequately explains the unilaterality, accounts for the nature of the symptoms, and fits with the fact that cures are most often effected by relieving tension upon the superior cervical ganglion, which controls the blood supply to the interior of the skull.

Symptoms. There may be a premonitory period of a few hours or a day, during which depression and general malaise are felt. The attack generally begins in the morning with headache, occipital or frontal, which spreads until one lateral half of the head is affected, less commonly the entire head. The pain is throbbing, intense, and blinding; it is increased by noises, jars, and light. Vision may be impaired. Nausea and vomiting are common. From the character of the vomited matter, these headaches are often called "bilious" but they are not, in fact, caused by either gastric or hepatic disorders.

The pulse is small, hard, and slow; the face is pale. A feeling of stupor and confusion of ideas develops and grows until the patient reaches a stage in which he can relax and sleep; this sleep usually ends the attack and the patient awakens free from the headache and feeling quite well. The average attack lasts from 6 to 24 hours.

There is in many cases a quite definite periodicity, hard to explain, except in the case of the monthly migraine of women. Attacks may occur weekly, or fortnightly.

The diagnosis is not difficult when periodic attacks of hemicrania occur; but there may be atypical or border-line cases which are hard to identify.

Hysteria.

This condition develops most commonly between the ages of 15 and 25 in females and at a somewhat later period in males, but may occur in children as early as 8. Neurotic ancestry predisposes and the exciting causes are profound emotions, anxiety, fear, worry, excitement, shock, excesses (*especially sexual*), hemorrhages, the infectious fevers, and various toxins such as lead, tobacco, and alcohol. Undoubtedly the principal factor is a congenitally unstable nervous system, the vitality of which is further undermined by some wastage of nerve energy.

Two types are described, **hysteria minor** and **hysteria major.** The dividing line is that in the major form, paralyses, contractures, and anesthesias appear while in the minor they are absent.

In **hysteria minor** the patient becomes highly excitable, mentally depressed, and extremely sensitive, and there is marked loss of mental control. She yields to impulses and laughs and cries readily and from insufficient causes. There are hyperesthesias and pains and the patient is "nervous". Sleep is disturbed; there may be somnambulism.

There is frequently headache, usually at the vertex. Areas of hyperesthesia are found on the breasts, over the ovaries, and along the spine. They are sensitive to pressure and are known as "hysterogenic zones." Vomiting spells may occur. Convulsions seldom occur in hysteria minor.

Hysteria major includes the preceding symptoms and adds to them paralyses, contractures, and anesthesias. The anesthesia most often affects one half of the body (*hemianesthesia*), but may be segmental or disseminated. The pain sense is most affected, with thermal and tactile senses less involved. The hemianesthesia is usually on the left side. Skin reflexes are absent. There may be hemiplegia, paraplegia, or monoplegia, so closely simulating organic disease of the central nerve system that only its transitory character serves to establish its hysterical nature. Paradoxical symptoms develop, such as curiously distributed paralysis, or the occurrence of a typically lower neuron paralysis with an upper neuron distribution, or without muscular atrophy. Muscular contractures appear and disappear. Sudden amyosthenia may precede a paralysis.

Hysteria is protean in its manifestations. There is scarcely a disease in the catalogue which it may not to some extent imitate.

A diagnosis can be made with certainty only after careful exclusion of organic disease and observance of some contradictions in the symptom-complex which mark the case as purely functional.

Cranial nerve symptoms are frequent. There may be impairment of vision due to an anesthetic condition of the retina, and this may affect either or both sides. The sense of taste may be abolished or impaired, perhaps only on the back part of the tongue. Parosmia and hyperacusis may be present.

The hysterical patient is excessively self-centered, moody, weak-willed and selfish. Such patients are highly suggestible and may, through auto-suggestion, come to believe themselves victims of conditions which have no actual existence.

Symptoms pointing to the digestive tract may be anorexia, dyspepsia, and constipation. After an hysterical attack a large quantity of clear, pale, urine, of low specific gravity, may be voided. As vasomotor symptoms there may be flushing, pallor, or œdema of the extremities.

The "crises" which occur in hysteria major are various; most common are those of a convulsive, emotional, neuralgic, or gastric type. Less common are paroxysms of coughing, sneezing, hiccoughing, or periods of catalepsy, trance, or lethargy. There is an ordinary form of convulsion which appears in hysteria and a special form called **hystero-epilepsy.** In the former the patient suddenly falls and various irregular movements of head and body occur. The eyes are closed, the pupils dilated, and there may be convergent strabisums or nystagmus. If the attack is severe the hands, arms, and fingers are flexed and the legs extended and rigid. The patient may scream or cry out during the attack but never bites the tongue, as do epileptics.

The duration of an hysterical convulsion may be from a half hour to several hours, during which the patient retains consciousness and may possibly be aroused if sharply spoken to. Marked mental excitement may either accompany or follow the attack. The severity of the seizure may vary from a chill-like rigor to a marked clonic convulsion.

Hystero-epilepsy is a true hysteria which closely simulates epilepsy. There is a prodromal period, an epileptoid stage lasting from 1 to 3 minutes, a stage of violent movements lasting from 1 to 3 minutes, an emotional stage lasting from 5 to 15 minutes, and sometimes a stage of actual delirium.

The facies of hysterical convulsion is somewhat characteristic. The eyeballs are rolled upward and the mouth drawn tight, giving the face a somewhat hypocritical appearance. The eye is sensitive to touch, in which it differs from that of epilepsy. The color of the face is flush rather than cyanosis.

The attitude likewise, during the tonic state, suggests an intentional posturing rather than an abandonment of control. The patient in falling is rarely hurt, as if the fall were studied. This appearance should not be taken to mean that the patient is "faking". Intentional deception and exaggeration of symptoms does often occur, as a result of disturbed mentality, but all the symptoms arise out of an actual disorder just as uncontrollable by the patient as a toothache.

Diagnosis. The history of previous hysterical attacks, and the presence of hysterical stigmata render the diagnosis fairly easy. Hystero-epilepsy is often mistaken for true epilepsy, and hysterical paralyses for the effects of organic nerve lesions. They should be distinguished by their transient and variable character. Any paralysis, contracture, or anesthesia which responds immediately to treatment or is spontaneously cured is probably hysterical.

It should be borne in mind that hysteria may be associated with other disease, so that the commingling of symptoms is confusing to the examiner. The most careful exclusion of other diseases is always essential to positive diagnosis. The age of the patient and a neurotic family or personal history always help.

Neurasthenia.

A condition of deficient nervous vitality, either congenital or acquired. The inheritance of a neuropathic tendency predisposes. Among exciting causes are all factors which waste nerve energy and many conditions which poison or irritate nerve tissue generally. Injury, shock, overwork, worry, excessive use of stimulants or narcotics, sexual excesses, dietetic imprudences, auto-intoxication from intestinal poisons, and such infections as syphilis, malaria, typhoid, or influenza, may lead directly to neurasthenia. In other cases it is difficult to ascribe any cause except an inability of the nervous system to sustain the demands upon it.

The disease rarely develops under the age of 20 or over 50, although occasional cases do extend beyond these limits. It is equally prevalent in the two sexes, but is much more common in cities, and among those who do mental work.

Symptoms. The first symptom is usually depression or headache, and headache remains one of the most persistent and aggravating features of the case. The headache is usually occipital or diffuse, and numerous cases describe a "band sensation" encircling the head just above the ears but not including the vertex. It usually begins in the morning and continues during the day, abating toward evening; rarely does it prevent sleeping. It is rather a characteristic of neurathenics that they feel worse in the morning and gradually better as the day advances.

With the headache there are paresthesias, especially around the head; feelings of pressure, tenderness, burning, or constriction. Paresthesias of other parts of the body may occur and there is a peculiar feeling of weakness at the back of the neck and down the cervical spine.

Mentally, the patient is depressed, sensitive, and given to brooding. There is inability to concentrate the mind, irritability or peevishness, and some mental confusion. Physically it is noted that bodily fatigue comes quickly and upon slight exertion; there is actual muscular weakness which may not be noticed except when work is attempted. The deep reflexes are exaggerated (*usually*) and the skin reflexes increased, but the condition of the reflexes is decidedly variable. There may be a tremor of the hands, tongue, lips, or eyelids. The eyes tire easily with use, although vision may be good; astigmatism, hypermetropia, and asthenopia are common. The sexual apparatus is weakened and nocturnal emissions are frequent; there may be partial or complete impotence. The pulse is irritable and may accelerate markedly for trivial reasons.

There are numerous vasomotor symptoms such as cold feet and hands, palpitation of the heart, pseudo-angina, hot flashes, noises in the head, vertigo, and periods of profuse perspiration. There is gastric and intestinal indigestion with a strong tendency toward obstinate constipation. As a rule the neurasthenic is underweight, but this is not necessarily the case.

Many sub-varieties of neurasthenia are described without real justification for the naming, which usually consists in affixing a word indicating the cause. Neurasthenia must be differentiated from hysteria, to which it seems to be related, from the initial stages of paresis, from melancholia and hypochondriasis, and from

fraudulent malingering. Nothing is easier to pretend than neurasthenia because its symptoms are so nearly altogether subjective that the examiner must take the patient's word, without much verification, for everything.

Prognosis. The disease tends to run a chronic course of from 1 to 10 years. Recovery is frequent, but so are relapses. Removal of the contributing causes has much to do with the cure; rest from all overstrain, moderate exercise, mental tranquility, and correct diet have an obvious place in the treatment. Removal of every possible nerve irritation or wastage is indicated.

Traumatic Neuroses.

This name is applied to a wide variety of aberrations in nerve function which are apparently due directly to trauma. These cases are especially so described when they follow railway or motor wreck, a heavy fall, or other application of violence to the body. The manner in which physical shock produces these varied nervous aberrations is not generally understood but in the greater number of cases nerves have undoubtedly been impinged upon by damage to the vertebral column and its surrounding tissues, and some part of the nerve mechanism is thrown out of functional balance with the remainder.

So-called "traumatic hysteria" is simply an ordinary hysteria, usually hysteria major, which has appeared abruptly following injury or shock. "Traumatic neurasthenia" is similarly produced and is otherwise the same as any other neurasthenia. "Railway spine" is virtually the same as "typhoid spine" except that in the one case the hypersensitiveness and irritability are the effect of physical violence and in the other of the toxins and inanition of the infectious fever. It must be remembered that a violent concussion may cause multiple minute hemorrhages within the central nerve system in which case organic symptoms are superadded to the hysterical or neurasthemic symptom-picture.

In diagnosis, the history of trauma and the symptoms of hysteria or neurasthenia are sufficient, if malingering be excluded. Information of value in some cases may be had by discovering whether those responsible for the injury have settled the damage claims or not. This cynical suspicion, however, should not prevent proper interest in every real case.

B. MOTOR NEUROSES

Chorea.

(*St. Vitus's Dance, Sydenham's Chorea*).

While this disease may appear at any age, it is commonest between 5 and 15, and girls are more often affected than boys. The exciting causes are worry, fright, injury, rheumatism, and nerve irritations such as result from intestinal worms, constricted prepuce, nasal disease, etc. Anaemia and malnutrition are often predisposing causes. Although this form of chorea has characteristics which would suggest bacterial origin, no specific agent has been discovered. Endocarditis too frequently develops in connection with chorea and is its most serious effect or complication.

Symptoms. Its onset is gradual in most cases, requiring from 3 to 4 weeks for full development, though an occasional case may come abruptly. At first, there are irregular twitchings of hand or foot, and winking, grimacing, or twitching of face muscles. This is at first confined to one side of the body but presently extends to the other side. Walking becomes difficult, with much stumbling, and the irregular movements increase. At the height of the disease the child is almost helpless, sometimes quite so and confined to bed. A slight fever may be present but is not usual. The choreic movements continue whether the patient is active or at rest, but are increased by effort and diminish or disappear during sleep. Speech is confused and difficult. There is commonly irritablity of temper and some dullness or confusion of intellect. In extreme cases there may be delirium with delusions and hallucinations (*maniacal chorea*).

Anorexia, constipation, loss of flesh, and anaemia develop. The reflexes are diminished and the knee-jerk may disappear. The muscles are weakened, but there is no actual paralysis except in the rather rare **paralytic form,** in children, in which one arm or one leg may suddenly become limp and powerless, perhaps with slight twitchings.

The disease may last from 6 weeks to 6 months, but averages from 10 to 12 weeks. Relapses occur in a considerable proportion of cases. The prognosis is excellent, however, as nearly all cases recover. The greatest danger is an endocarditis which may permanently affect the heart valves.

The diagnosis of chorea is not difficult as the movements are somewhat characteristic. They must be distinguished from the slower, more purposeful movements of athetosis, and from hysterical spasms.

Huntington's (Hereditary) Chorea.

Develops between the ages of 30 and 50, in men as often as in women, and seems to be directly hereditary. Begins with twitchings in the face, then in the hands, arms, and legs. With the growth of the disease there is progressive impairment of the mental faculties, with a tendency to melancholia and an eventual dementia. Although the disease may be protracted from 10 to 20 years, the ultimate prognosis is bad.

Habit Spasm—Tic.

Repeated co-ordinated movements, such as a gesture, shrug, sniff, grimace, wink, or a jerk of the head. Is usually seen in nervous children and may be the aftermath of a chorea or may be a true convulsive tic from the start. Direct effort of the child's will to overcome what is often a noticeable and embarrassing habit, is usually futile. With general improvement in vitality and in stability of the nervous system the habit spasm is likely to disappear, though in some cases it may persist through life.

Saltatory Spasm.

A jumping spasm which occurs in hysteria and neurasthenia and in patients of all ages. The jerk is excited by the weight of the patient upon his feet, which excites violent contractions of the hip and leg muscles and produces a jump.

Torticollis.

(*Wryneck*).

This is a tonic or clonic spasm of neck muscles, especially the sternocleidomastoid and trapezius. The simplest form is a spasmodic wryneck due to irritation of the eleventh cranial nerve. There is also a **spurious wryneck** caused by caries of the cervical vertebrae; a **symptomatic wryneck,** occuring in rheumatism, adenitis, abscesses and tumors of the neck; and a **congenital wryneck,** due to injury to the spine at birth, usually by twisting with the obstetrical forceps.

Excluding abscess and vertebral disease, the diagnosis is easy. The characteristic pose of the head, which is drawn to one side and partly rotated with the chin toward the opposite side and somewhat elevated, and the palpably rigid and shortened sternomastoid muscle, are unmistakable. The muscles being permanently contractured in many cases, the head can be moved freely to the limit of the muscle's length, whereupon movement will be abruptly checked.

Prognosis. Never a fatal disease, it is difficult to cure. With patience, many cures can be affected and at the least much benefit can be derived by all except those cases which are symptomatic of organic disease which in itself is beyond cure.

Paralysis Agitans

(*Shaking Palsy, Parkinson's Disease*).

Whether this disease should be classified with the neuroses or among organic nervous disorders, is a moot question. It has no distinctive pathology except a premature senility of the nerve organs, but is so definitely recognizable as a disease entity that logic suggests that it must be based upon some positive changes in nerve structure.

A disease of late life, it usually begins between the ages of 40 and 70, most commonly between 50 and 60. Cases reported in men of 20 and 30 are probably errors in diagnosis. Commonest in males. Anxiety, overwork, and hereditary influence predispose. Fright, injury, mental suffering, exposure to cold and wet are often exciting causes.

Symptoms. Aching pains appear in the arm, usually the left, with tremor of the fingers. This tremor extends gradually upward to involve the entire extremity, and then passes to the other side. Eventually the whole body may be affected by it, though the face frequently escapes. The tremor ceases upon voluntary movement but continues when the parts are at rest. Muscular rigidity develops.

A characteristic facial appearance develops, which is known as "Parkinson's mask". The face is stiff and expressionless. The gait is peculiar; the trunk is bent forward, the knees slightly flexed on the leg, and the forearms are flexed on the arms, the fingers straight. The patient walks with a stiff shuffle, and finds it very hard to rise from a chair, to start walking, to stop, or to turn. The

bending forward of the trunk and the flexing of the neck, make him walk with forehead presented and it is difficult for him to see anything above the level of his eyes.

The voice is altered; it becomes weak, monotonous, and high-pitched. Difficulty is experienced in starting a sentence but when it has been started it may be finished with great rapidity.

The patient may feel heat, cold, fatigue, and restlessness. The face is usually red and flushed, and there may be periods of profuse perspiration or other vasomotor phenomena. Polyuria may appear.

Diagnosis. From multiple sclerosis, paralysis agitans may be distinguished by the fact that the tremor in the former is of the "intentional" variety, and there are apoplectiform attacks and paralyses, scanning speech, nystagmus and other ocular troubles. In plain senile tremor the head is first affected, not the hands, and the patient is older. Posthemiplegic tremor is recognized by the history of hemiplegia and the symptoms are unilateral.

Prognosis. This disease tends to run a long course and does not shorten life appreciably. It appears to be incurable, which fact recalls the early statement that it is apparently a premature senility of nerve tissue.

Occupation Neuroses.

A group of functional nerve disorders in which a particular muscular movement, or set of movements, induces weakness and spasm so that the movement cannot be performed. The use of the same muscles for other purposes may still be possible, as there is no real paralysis of the muscles. Writer's cramp is the best known example. Among other occupational neuroses are musician's cramp; telegrapher's paralysis; sewing spasm (*in tailors and seamstresses*), milker's spasm, and ballet-dancer's cramp. Pedestrians, typists, and billiard-players, dentists, etc. may develop special neuroses.

The first symptoms are a slight stiffness in the fingers (*writer's cramp*) with occasional twitchings or jerky, uncertain movements of the pen when writing. This may persist for a long time. The patient is likely to be depressed and fearful of paralysis. Eventually it becomes impossible to write and any attempt to do so leads to spasms of the muscles of the fingers and arm. The arm aches and is tender to pressure, but there is no real paralysis and other complex movements can be performed.

There is a **spastic** form of writer's cramp in which there is tonic spasm of the fingers; a **neuralgic** form with great pain when writing; and a rare **paralytic** form in which the muscles become overwhelmingly weak when writing is attempted and the pen drops from the fingers. An intention tremor accompanies some cases.

The general health may be quite good although neurotic symptoms other than the special occupational neurosis are usually manifested. Mentally, the patient may be nervous, emotional, and at times very much depressed. There may be insomnia, vertigo, paresthesis, and perhaps headache. In some cases there is evidence of a trophic nerve involvement in the form of passive congestion of the arm and hand, dry, crackling skin, and brittle nails.

A cure usually requires prolonged treatment, with abstinence for a long time from the causative occupation.

Tetany.

A disease characterized by bilateral tonic spasms of the extremities. These may intermit or be continuous, but are never clonic. The true origin of tetany is obscure; it may result from thyroidectomy, especially if the parathyroids are also removed; it follows acute infectious diseases sometimes, especially typhoid; it has appeared in epidemic form; and it often follows debilitating or wasting diseases such as chronic diarrhoea or rickets.

The posture of the patient is somewhat characteristic. The arms are folded, the elbows and wrists flexed, the thumb bent into the palm, the fingers close together and extended except at the metacarpo-phalangeal joint (*accoucheur's hand*). In the foot the toes are flexed. In the more severe cases the muscles of the neck, face, and jaw may be spastic; if those of the thorax are included, there is cyanosis from the interference with respiration.

The paroxysms of tetany may be produced by pressure on the affected parts along their main nerve trunks, or by impeding the circulation through the blood-vessels. The excitability of the motor nerves is greatly increased so that a light tap may cause severe contractions. An attack of tetany continues for a few hours to two weeks or more in the severer forms. Of these latter, gastric tetany, from pyloric stenosis, usually associated with ulcer or cancer, is one of the worst; the tetanic paroxysm may be accompanied by intractable vomiting.

Diagnosis. To be distinguished from tetanus, in which there is history of trauma and in which the contraction begins in the jaw

muscles. The attitude of the hands is quite different and the signs of profound toxaemia found in tetanus do not appear in tetany. Carpo-pedal spasms in rickety children or those who have gastro-intestinal catarrh, are transitory, and should not be confused with tetany.

Prognosis. Ordinary tetany recovers, but that which is due to malignant disease of the stomach or to a serious obstruction to the passage of food from stomach to duodenum is likely to prove fatal, or rather, its causative disease may terminate life.

Paramyoclonus Multiplex.

A name given to a somewhat obscure borderline group of motor neuroses, of choreic or tic-like character, usually involving large muscular movements, especially of the trunk. The cause has not been discovered but heredity seems to play a part in many cases. Numerous varieties of paramyoclonus are described but the distinctions are artificial and uncertain.

THE TROPHONEUROSES

This term is applied to a group of diseases in which the essential factor is a disturbance of the trophic influence of the lower neurons over the tissues they supply. It does not include the atrophic effects of organic lesions which destroy the conductively of the lower neurons.

Raynaud's Disease.

A rare condition occurring especially in children and young adults, and in women oftener than in men. Anaemia, chlorosis and neurasthenia predispose, and the exciting cause may be an acute infectious fever, menstrual disorders, shock, syphilis, or diabetes.

The onset is rapid. Two or three fingers of each hand are usually affected. There is coldness, numbness, and a waxy pallor of the fingers. There is anesthesia, the fingers feel lifeless, and the skin is shrunken. The condition may intermit for a time but finally becomes fixed. In some cases all the fingers are involved, in others the toes, tip of nose, or ears.

In the severer cases the fingers become swollen and blue, with much pain. Gangrene follows. Small blisters form on the finger tips, which fill with a bloody serum and then dry up, forming scabs. An ulceration occurs under the scab, which heals and leaves a scar.

The disease tends to run a long course but is rarely fatal.

Erythromelalgia.

Red neuralgia of the feet occurs in diabetic and gouty individuals, and in those who have been too much afoot. There are severe, continuous, burning pains in the ball of the foot and following the distribution of the plantar nerves. The pain is worse at night, and during the day is aggravated by standing or walking. There is flushing of the feet upon exertion, and in some cases the feet present a continuously dusky, mottled, red swelling.

Angio-Neurotic Oedema.

This is a sudden, circumscribed oedema, occurring in nervous subjects, most often in winter.

A swelling abruptly appears, varying from a half inch to two or three inches in diameter. It is painless, although there may be a sensation of itching, burning, or stiffness and tension; the latter is very common. The swelling may be located on the end of the nose (*very common*), or elsewhere on the face, hands, feet, body, larynx, or genitals, in the order named. If the larynx is the seat or the swelling affects the larynx it may be exceedingly dangerous by cutting off respiration. Otherwise, the condition is transitory and harmless. There may be one swelling at a time or several. Each lasts from a few hours to several days. There is a marked tendency to recurrence.

Acromegaly.

(*Marie's Disease*).

This should probably be classified as a disease of the endocrinous glands rather than as a trophoneurosis. It appears to follow disease of the pituitary body (*hypophysis cerebri*) and whether due to involvement of the nervous lobe or the glandular is not positively known.

It usually begins between 18 and 25, with gradual enlargement of the head, feet, and hands, accompanied by headache, malaise, slight rheumatoid pains, anaemia, polyuria and dry skin. The sexual power dwindles in men and menstruation ceases in women. The bones thicken, especially at their extremities, and the soft tissues of tongue, lips, and nose hypertrophy. The lower jaw increases in size more than the cranium and the facies of acromegaly is rather distinctive in well developed cases.

Vision may be affected if a tumor of the hypophysis presses upon the optic chiasma. The voice is changed and the speech slow, hesitant, and gutteral.

MENTAL DISORDERS

The field of the mentalist is a special one. To delve deeply and comprehensively into all the manifestations of mind and into all its aberrations and their value and significance, is beyond the province of a book of this character, and beyond the necessities of the general practitioner. We shall attempt instead a brief discussion of the processes of the mind and follow by sketching the commonest symptoms of mental disease and their significance.

It has been pointed out in earlier chapters that the primitive nerve system was simple in its structure, requiring only an afferent or sensory neuron and an efferent or motor neuron, the two connected by contact so that impressions received over the one might be transmitted to the other as a basis for action; that the formation of numerous of these simple nerve-arcs and the necessity for their co-ordination for the maintenance of the primitive animal body necessitated the development of intercalated neurons to pass between the afferent neuron and one or more efferent neurons across an intervening distance. This intercalated neuron made possible multiplicity of response to a stimulus from the periphery, and the establishment of co-ordination between divers parts of the increasingly complex and differentiated animal body.

As the number and complexity of the intercalated neurons increased in pace with the evolution of animal life, many of them surrounded the cell clusters already withdrawn from the periphery to form a central core, in such a way as to form the associative tracts of the spinal cord and the tracts connecting the cord with the brain and vice versa. But at this stage the brain itself consisted of little more than a superior prolongation of the spinal cord, similarly consisting of a group of central ganglia surrounded by the tracts of nerve fibres which served to link these ganglia with each other and with the lower centers of like character. The headward end of this central axis underwent a more rapid development than the remainder because it was in direct connection with those sensory nerves which, being projected forward into first contact with the environment, received the bulk of the sensory impressions impinging upon the animal. The olfactory, optic, and gustatory receptive mechanisms were earliest and most important in appearance; as a conse-

quence the anterior or cephalic portion of the central axis early assumed a predominant development and began to gather to itself a regulatory power over the lower elements of the nerve system.

Gradually the supervisory function had been withdrawn from the collateral ganglia to the prevertebral chain of sympathetic ganglia; from the sympathetic to the cell groups of the spinal cord; and from the cord brainward. The ultimate physical development within the nerve system was the **neopallium**, consisting of an extra layer of gray matter, made up of nerve-cells and their connections and supporting tissue, and connected with the lower centers by a multitude of projection fibres and with each other by a multitude of associative and commissural fibres. The neopallium finally became the seat of all those higher functions of nerve tissue which have to do with the relation of Man to his environment, as distinguished from the function of the lower neurons which is to maintain the vegetative functions of the body. The action of the lower centers is unconscious, while that of the higher centers is partially conscious.

Consciousness is believed to reside in the cerebral cortex alone. That cortex is the direct instrument of what is termed Mind, but through the connections of the cortex with all the lower nerve centers the mind influences every activity of every part of the body, but in varying degrees. Thus the activities of skeletal muscles are under direct control of the mind; the reception and perception of sensory impressions from the outside world belong to the domain of mind, as does the formation of **judgments** concerning these impressions. The functions of digestion, assimilation, circulation, secretion, etc., appertaining to the growth, nutrition and repair of the body, are directly regulated by lower nerve centers in the central axis and in the sympathetic ganglia which are merely detached portions of the central axis, and are but very indirectly controlled by the mind.

The question as to whether Mind is merely the result of the total accumulation of sensory impressions, and memories of them, and of memories of resultant actions, and therefore to be regarded as the product of the nervous system, or whether Mind is a force, separate from physical and chemical forces, unanalyzable except through its expressions, and capable of inhabiting and animating a physical body under normal conditions, and making use of the brain as a special instrument for its expression, has agitated philosophers of all ages. It is, perhaps, impossible to settle this question

conclusively in the light of present knowledge. Scientific research has disclosed an actual, material basis for almost all the phenomena of mind; there remain, however, some unexplained phenomena, and certain evidences of the existence of a special life force which accounts for the difference between a quick and a dead body, and which may have existence independent of the body. That this life force cannot be recognized or appreciated by human senses or human devices except as it expresses itself through the medium of the brain does not establish its non-existence outside the brain or prove it the creature of the nerve system and that alone.

We prefer to hold to the view that the Mind is the essential Man and operates the body; that its chief instrument of expression is the brain, and more particularly the cortex of the brain; that disorders of mind, so-called, are in reality disorders of the brain which interfere with the proper expression of mind through its instrument. It is necessary to practical instruction that the demonstrable influence of heredity and environment be fully recognized and utilized; that the limitations of our understanding of the mind be left understood oftener than expressed; and that the disorders of the brain unassociated with discoverable organic changes should be considered as **functional** disorders, and as if they belonged to the mind rather than to any particular part of the brain structure. However, the student will remember throughout the ensuing discussion that the writer believes that the disordered expression of mind has a physical basis, whether discoverable or not, and is due to some alteration in the mechanism through which, and only through which, the mind can express itself perceptibly to human intelligence.

DISORDERS OF PERCEPTION

That portion of the cerebrum the function of which is to receive and interpret afferent impressions from the outside world is known as the **sensorium.** Its boundaries are ill-defined. In general, the sensorium includes an area paralleling the general motor area and occupying the pre-central convolution; an auditory receptive area in the temporo-sphenoidal lobe; a visual area in the region of the cuneus of the occipital lobe; olfactory areas in the limbic lobe; and doubtless other less recognizable areas. It is not to be understood that each cortical sensory area is completely given over to that function to the exclusion of all others; there is a certain degree of mingling of sensory, motor, and perhaps intermediate functions.

It is only possible to determine that a given area is **chiefly** sensory. The preceptive and volitional areas are commonly spoken of together as **sensori-motor area.**

There are, however, despite this mingling, certain disorders of perception which do not directly include motor abnormalities or aberrations of volition. Among these are:

Illusions.

An illusion is an inexact, false, impression. There is a misinterpretation by the mind as to the meaning or source of a sensory impression. Something real in the environment is perceived, but incorrectly. An illusion has an actual basis in fact. For example, a rope being drawn through a manhole in the street may be perceived as a snake, the whistle of a distant train may be perceived as a human voice.

Hallucination.

This disorder differs from illusion in that it has no actual foundation in fact. Instead of being a misinterpretation of something that has real existence, it is a perception of that which does not exist at all. Sounds are heard when there are actually no sounds in the environment. Curious or offensive odors may be smelled where a normal person can detect none whatever.

Some hallucinations undoubtedly arise from pathological changes in the sensory end-organs themselves; this is especially true of hallucinations of sound, which may arise through abnormal changes in the ear, or in the end-organs of the acoustic nerve. Wells illustrates this by an imaginary invasion of a new germ into the substance of the eye, where it is seen by his characters as a terrible, gigantic monster. Hallucinations arising within the end-organs are referred to as entoptic, entotic, etc.

In practice, illusions and hallucinations are produced by the same causes, and involve the same mental process, so that distinction between them is unnecessary.

Clouding of Consciousness.

Not all sensory stimuli passing toward the sensorium have power to evoke recognition. Subminimal stimuli of divers sorts are constantly impinging upon the sensory end-organs without evoking consciousness, as the vibration of the air particles fre-

quently is unfelt. An impression must be sufficiently strong in order to affect the sensorium but the strength required for this varies a great deal under different circumstances. During sleep the responsiveness of the brain is greatly diminished, and the "threshold of consciousness" is said to be withdrawn. During waking hours this threshold is greatly advanced and slight stimuli may be appreciated, but here also there is variation. Attention or lack of attention lowers or raises the stimulant strength required for recognition. Pain reduces the perceptibility of other types of stimuli.

In certain pathological conditions the threshold value of stimuli is greatly altered. In delirium, especially, the patient is so attentive to his hallucinations and delusions that ordinary stimuli may be totally unperceived. If such a patient is shaken and a question asked forcibly, he may be quite able to give a proper answer, showing that his thinking process is normal enough, but perception diminished, requiring an unusually strong stimulus to arouse it.

Clouding of consciousness—a lowering of the threshold value of all sensory stimuli—may exist in all degrees from a very slight clouding up to complete coma, from which the patient cannot be aroused at all, and in which he is oblivious to all stimuli.

Disorientation.

Orientation refers to correct apprehension of one's environment, temporal, spatial, and personal. The first requires knowledge of the time in which the patient is living, year, month, and day; his age, etc. The second can be determined by asking where he lives—street, number and city—in what place he now is, etc. The third includes knowledge of his own identity and of that of the persons surrounding him who have been, or should be, familiar to him. Inability to answer such questions is termed "disorientation." It must not be confused with amnesia, loss of memory, nor must any explainable ignorance be mistaken for disorientation.

DISORDERS OF THOUGHT

After sensory impressions are received from the environment they must be associated with previously stored up experiences, or with each other, and identified. The assimilation and re-arrangement of percepts with those already in consciousness is the **process of thinking.** When a new idea is brought forth by this re-arrangement, the process is **reasoning** and the result a **judgment.**

Delusions.

A delusion is a false belief, any false belief, and is not necessarily due to any disorder in the process of thought; it may be based upon misinformation or incomplete experience. A man may believe a set of figures adds up to a certain sum when in fact it is less; that is merely an error in calculation. His belief, of course, is a delusion while it lasts, but has no pathological significance whatever. The early opinion that the earth was flat was a delusion but not an evidence of mental disease.

Delusions may be sane or insane. It is sometimes difficult to distinguish the one from the other, but there are three principal features about insane delusions which help to identify them. First, they are manifestly not true to facts, often utterly absurd, as the delusions of different identity (*a modern man believes himself to be Napoleon Bonaparte*). Second, they cannot be corrected by an appeal to experience; the patient cannot be argued out of his delusions. Third, they fail to harmonize with the known experience and education of the individual.

Sometimes a false belief fails to show any of these features and yet is an insane delusion. It is necessary in such a case to study the origin of the belief to determine if it is reasonable.

A **fixed** delusion is one firmly held and unalterable; **changeable** delusions are constantly shifting and altering. An **unsystematized** delusion is one which is not related to the conduct or other beliefs of the patient. Thus, a man may believe that he is dead, yet continue to act in all things the part of a living man. On the other hand a **systematized** delusion is one which colors the conduct and reactions of the individual in all possible ways; he argues its correctness, and acts upon the assumption of its accuracy. Thus, a man possessed of a delusion of great wealth may persist in trying to buy costly things, to bestow large charities, to command expensive service and attention. He orders all his conduct upon what he conceives to be the proper plane for a man of wealth. His delusion is systematized.

Obsessions.

Obsessions are fixed ideas which obtrude upon the mind of the patient persistently and against his will. They are understood by the patient for what they are but he is unable to resist them and in time is compelled to act upon them. Best known of the obsessions

are the phobias, or fears, such as; pyrophobia, fear of fire; agoraphobia, fear of wide open spaces; claustrophobia, fear of narrow or confined spaces. To be classed as a phobia a fear must be groundless and abnormal, as in the case of one beset by fear merely because of his presence in a small room.

Obsessions of doubt are common; one may doubt the accomplishment of a thing he himself has done, and continue to doubt it after his own verification of the fact. Fixed ideas are not always obsessions, for they are often believed to be perfectly reasonable and natural. A person who, having seen pictures of victims of Bright's disease suffering from backache, and who, upon developing a backache, becomes imbued with the fixed idea that he has Bright's disease, is not necessarily obsessed; he is, perhaps, deluded by incomplete knowledge.

Dream States.

The term "dream states" is applied to conditions in which the threshold value of sensations is changed so that no ordinary impressions reach consciousness, but in which phychomotor reactions take place which arise from the content of consciousness—usually dreamy ideas and multiform hallucinations, similar to those which occur in dreams. This condition may arise to the height of an ecstacy.

Flight of Ideas.

Ordinary thought proceeds consistently toward a **goal idea.** Thoughts are logically connected and sequential. In flight of ideas, a patient either has no goal idea or soon loses it, and the thought wanders erratically, responding to the influence of chance associations. It is often possible for the examiner to detect these associations and he may even be able to produce them by showing an object or causing a sound which will at once be linked up by the patient with his thought sequence. Sometimes the association of ideas is entirely internal, that is, in the patient's mind, in which case it may be possible for the examiner to perceive it. The following illustration will show both internal and external associations and at the same time illustrate the irrational stringing together of ideas. "My name is John Doe. I can name the Presidents of the United States. (*Association of the word name in two forms, noun and verb.*) George Washington, John Adams, Joseph Jefferson, Henry Irving. (*Note the shift of ideas at "Jefferson" from Presi-*

dent to actor, and the subsequent continuance of the actor idea in the name of Henry Irving.) Irving wrote the "Legend of Sleepy Hollow." I am so sleepy I can scarcely hold my eyes open. See the curve of that cat's tail. (*External association caused by a passing cat.*) Cats like milk. Milk of magnesia is good for babies."

In such a patient any sensory impression is likely to become the point of dissociation, and the patient may be distracted at will by some act of the examiner.

Circumstantiality.

Circumstantiality resembles flight of ideas in that there is frequent change of directions of the train of thought, but differs from it in the fact that there is a goal idea and this is ultimately reached, though often by routes so devious that the connections between ideas can only be traced with the utmost difficulty. A patient given to circumstantiality is unable to narrate anything without entering into every detail suggested in the course of the story. Children who have not yet developed appreciation of the relative value of ideas, often indulge in a moderate degree of circumstantiality without its indicating anything but an immature sense of values—or intentional evasion of embarassing questions. Poorly educated women sometimes show this trait. Senile old men may have it so marked that the goal idea is finally lost and the case resembles flight of ideas. In all cases there is a tendency to maintain the train of thought and to arrive somewhere at the end.

Retardation.

A slowness of thought, coupled with doubt and hesitation. If asked a question, the patient will wait before replying and then answer very slowly. If asked to count, he may wait several seconds before beginning and then count very slowly, as if with the greatest difficulty. This psychic retardation is often coupled with motor retardation, every motion being slow.

DISORDERS OF VOLITION

Decreased Psychomotor Activity.

Corresponds to retardation of thought, above. There is especially a retardation in the liberation of voluntary muscular movements.

Increased Psychomotor Activity.

Opposite to the above condition, a too quick and facile release of motor impulses. The patient is restless, active, even violent. This is an outstanding characteristic of mania.

Impulsions.

Tendencies or urges to action which are almost or quite uncontrollable. Common in mania. The act may be of a particular kind and thus give a name to the mania; pyromania, a morbid impulse to start fires; kleptomania, a morbid impulse to steal; dipsomania, an impulse to drink; etc. Until an impulsion is yielded to, the patient is restless and disturbed, but when it has been carried out he may experience remorse.

A Compulsion.

Is related to an impulse but differs in that it seems to be laid upon the patient from outside instead of arising within his nature. Thus a patient may feel impelled to commit a crime, as murder, and may strongly resist the urge and even take precautions to prevent himself from doing it. Compulsions, resisted, cause a group of symptoms amounting to a crisis, in which the patient is weak, trembling, and dizzy, and perspires freely; finally he yields and the symptoms disappear.

Stereotypy.

Consists in the indefinite continuance or repetition of an attitude, a set of motions, or certain phrases. Repetition of peculiar or characteristic motions is commonest; these are spoken of as **mannerisms.**

Negativism.

Is a curious condition in which the patient always does the exact opposite of that which is required of him.

Suggestibility.

Is the opposite of negativism. It varies greatly in degree, from a mere tendency to imitate unconsciously homely and familiar acts performed in the patient's presence, such as yawning, rubbing the chin, etc., to a complete subjectivity to suggestions and commands, in which the patient becomes a mere lay figure in the hands of a master. About 15% of all persons are suggestible in some degree, or can become suggestible at will.

Stupor.

Is a condition of partial unconsciousness, less complete than coma, in which the outstanding feature is psychomotor inhibition voluntary motion is in abeyance.

EMOTIONAL DISORDERS

Exaltation.

A state of morbid emotional elation out of all proportion to reasons actually existing in the environment. The patient feels extreme happiness or exaggerated well-being. This is often a symptom of mania.

Depression.

Is the opposite of exaltation. Appears in melancholia. It is a morbid unhappiness without sufficient cause.

Emotional Deterioration.

Occurs often in cases of cerebral impairment, and develops an inability to react to conditions which should normally arouse the emotions—a morbid indifference.

DISORDERS OF MEMORY

Amnesia.

Loss of memory. It may apply only to a certain type or class of memories, or to a certain period of time, or it may be general. When it covers a definite period of time, amnesia is usually due to a serious illness or injury; in such cases the blank time may extend backward to a time greatly preceding the illness or injury—retrograde amnesia.

Paramnesia.

A memory disorder in which events are remembered which never happened. When these memories are associated with explanatory delusions, as often happens in paranoia, they are called retrospective falsification of memory.

Hyperamnesia.

An unnatural retentiveness for all details, such as may be seen in cases of chronic delusional insanity, who seem to remember every minute detail of their lives as having a bearing upon their pet delusions.

THE PSYCHOSES
DISEASES OF THE MIND

In the preceding pages the symptoms of mental impairment which most commonly occur have been discussed. It is now necessary to take up certain disease conditions in groups established by the relation of their causes to each other. There are, for example, certain psychoses due to the effect upon the body of infectious diseases or profound exhaustion. These present acute confusion as the principal characteristic.

Febrile Delirium.

Really an acute, confusional insanity, in which there are multiform delusions and hallucinations, disorientation, clouding of consciousness, excitement, restlessness, and agitation. It results in varying degrees, from fever and, if uncomplicated by other causes it varies in intensity with the degree of the febrile movement. The degree of fever required to develop delirium varies widely according to the mental stability of the patient; neurotics develop it more easily than others. In severe febrile cases, as in grave typhoid, the restlessness may subside to a mere aimless twitching and subsultus tendinum, and the delirium to a low muttering. This is usually an alarming development.

Infectious Delirium.

Due to the action of toxins upon the brain. May appear in an infectious disease before the fever has developed or while it is insufficient in degree to have caused the delirium. It is usually an acute confusion but there may be delusions of an unpleasant or terrifying character. Occurs in typhoid, typhus, smallpox, malaria, and hydrophobia. In the latter it may take the form of a change of character with restlessness, irritability and depression, developing into confusion and excitement.

Exhaustion Psychoses.

These develop as a result of profound depletion of vitality from any cause. Some, the post-febrile psychoses, may be continuations of febrile delirium after the fever has subsided, or may develop from exhaustion in the post-febrile period. Others follow extreme loss of blood, parturition, prolonged anxiety or worry, or severe

mental shock. Exhaustion psychoses vary greatly in intensity. They usually begin with insomnia and restless irritability, proceed to a mild confusion, with some clouding of consciousness, disorientation, hallucinations and delusions, and often develop psychomotor excitation with great activity and perhaps acts of violence. Stupor may occur transiently and there may be periods of complete lucidity.

In some cases the confusion develops to a high grade of agitation, a fever occurs, and symptoms resembling the typhoid status appear—to be followed by exhaustion and death.

Auto-Toxic Psychoses.

In certain conditions, poisons absorbed from the intestines as a result of gastric or intestinal indigestion, or toxins generated in the depraved metabolism of diabetes mellitus, or end-products of protein metabolism which are retained in the circulation because of failure of the kidneys to excrete them, may so affect the brain as to produce quite positive psychoses. The origin of such a psychosis in a given case must be determined by recognizing the causative disease.

Gastro-Intestinal.

Associated with an offensive diarrhoea there may be an acute confusion, indicanuria and perhaps albuminuria, vomiting, and low fever. Extreme cases may proceed to high fever, delirium, the typhoid status, and even to death from exhaustion.

Diabetes Mellitus.

With chronic diabetes there is most commonly a mild chronic mental disturbance, of depressive type, with melancholic ideas. Somnolence is common. Delusions of persecution frequently develop. The diagnosis depends upon the combination of depressive mental symptoms with persistent glycosuria.

Uraemia.

The symptoms of uraemic psychosis are acute confusion with changeable delusions, hallucinations, clouding of consciousness, and restlessness. In subacute cases there may be merely suspicion and anxiety, or systematized delusions of persecution. Diagnosis depends largely upon the urinalysis. Without that evidence most subacute cases cannot be distinguished from chronic insanity.

The Thyroid Psychoses.

Lack of thyroid development produces **cretinism;** associated with the marked physical evidences of this condition are mental symptoms ranging all the way from complete idiocy to mild grades of imbecility.

Removal of the thyroid in adults, or its atrophic degeneration due to disease, leads to a condition called **myxoedema,** obviously related to cretinism. Its mental symptoms are a state of indifference, apathy, and stupidity, deepening finally into dementia.

Toxic Psychoses.

Mental disturbances due to the introduction of poisons into the body may take on forms recognizable as attributable to particular types of poison. Commonest of these types are alcoholism, opiumism, and cocainism.

Alcoholism.

The effects of a given quantity of alcohol vary widely in different individuals, but while the symptoms differ in degree of development they are more or less similar in nearly all cases of ordinary drunkenness. All alcoholic symptoms are really of the paralytic type. First, only the higher mental functions, which are largely inhibitory, are reduced; the result is flight of ideas, increase of activity (*due to loss of normal inhibition*), reduction of the moral sense, and inattentiveness. Next, the lower centers become paralyzed, with sensory disturbances, such as reduction of the senses of touch and pain, and motor disturbances, showing themselves as muscular inco-ordination and anarthria.

If the alcoholic intake is sufficiently heavy it may lead to coma, which in rare instances terminates fatally. Alcoholics are emotional, the mood being perhaps pleasant, perhaps depressed.

Pathological Drunkenness.

There are certain persons so predisposed and susceptible that alcohol produces in them effects out of all proportion to its usual results. Delusions, especially of persecution, and hallucinations, may dominate the consciousness, or a little alcohol may result in a maniacal frenzy, perhaps with acts of violence. In epileptics alcohol usually initiates convulsions. In some cases paralytic symptoms are early and profound.

Delirium Tremens.

As a consequence of prolonged and excessive drinking of alcohol, with insufficient food and rest, a condition may develop which is characterized by tremor, delirium, and albuminuria. Rarely it occurs as a result of a single debauch of excessive drinking. It may follow the sudden complete withdrawal of alcohol from the chronic inebriate.

Delirium tremens may invade suddenly, but there is usually a prodromal period of nervousness, restlessness, anorexia, coated tongue, disturbed sleep and insomnia. Presently the three cardinal symptoms of tremor, delirium, and albuminuria develop.

The **tremor** appears particularly in the small muscles of the hand, face and tongue. It is increased by muscular tension. In some cases it may spread over the entire body.

The **delirium** is of the acute confusion type, with hallucinations, mostly visual. Characteristically, they take on the form of animals, often distorted from their natural shapes, and of loathsome reptiles or insects.

Physically, the patient is in a state of acute exhaustion, while mentally he is wildly excited, usually terrified into frenzy. This terror of the horrible, menacing objects which seem to surround him leads to strenuous activity and constant movement, shuddering, shrinking, striking at surrounding hallucinations and even at his attendants. Such patients must often be forcibly restrained to avoid injury to themselves and others.

The pulse is rapid and of low tension, the temperature normal or only slightly advanced.

Albuminuria appears in at least 50% of all cases. Leucocytosis is sometimes present.

There is an abortive type of delirium tremens, beginning with all the characteristic signs, but speedily recovering.

Chronic Alcoholism.

Every organ of the body is somewhat affected by the chronic use of alcohol, especially the stomach, pancreas, liver, kidneys, blood-vessels, and the nervous system. The outstanding symptoms are tremor, gastric catarrh, arteriosclerosis, albuminuria and a progressive mental enfeeblement.

The effects of alcohol on the nervous system manifest themselves as disturbances of sensation, motion, and intellect. The **sensory** symptoms are paresthesias (*pricking, tingling, formication*), patches of hyperesthesia and hyperalgesia, and anesthesia, sometimes patchy and often affecting only one side. The special sense nerves, more particularly the optic and acoustic, may be involved, with photophobia, amblyopia, and amaurosis; and subjective sounds (*roaring, hissing*) collectively known as tinnitus aurium. Visual and auditory illusions and hallucinations may occur.

The **motor** disturbances are cramp, spasms, tremor, and sometimes epileptiform convulsions; finally, general motor enfeeblement with paresis.

Mental changes are gradual and progressive. The intellect is clouded, the judgment impaired, the moral sense blunted; there may be marked delusions, most characteristic of which seems to be that of marital infidelity, or some delusion in which the sexual element is dominant.

Diagnosis. Alcoholic dementia can only be distinguished from other forms of dementia by its history. There is an alcoholic pseudo-paresis which is very like true paresis, but may be recognized by the alcoholic history. Alcoholic epilepsy may so resemble true epilepsy as to be indistinguishable, unless it is discovered that the attacks cease when alcohol is withdrawn. It should be remembered that a true epileptic may imbibe alcohol, which usually excites his attacks; such a case is not cured by abstinence from alcohol, however. There is a pseudo-paranoia due to alcohol which is very like a true paranoia, but may develop much more rapidly to a complete systematized delusion.

Dream states, followed by amnesia, may occur in alcoholics, in which there is no outward evidence of the fact that the personality has been altered. The patient may do, in that state, serious and important acts of which he has no memory afterward, such as the signing of a contract or deed, taking a long journey, or completing important business transactions. Usually the subject wakes up suddenly, or after a night's sleep realizes his proper person, but is without memory of anything which has occurred in the dream interval.

Opiumism.

A single dose is followed by mild stimulation of the mental faculties and then by a reaction characterized by a half-waking,

half-sleeping stage, with multiform hallucinations, usually very pleasant; these are commonly visual; they are not carried into the waking state. Afterward malaise, dry mouth, headache, constipation and nausea exact payment for the pleasure.

Continued use of opium or its derivatives leads to a yellowish-brown cachexia, evidences of asthenia and under-nourishment, and a chronic mental state more noticeable when the drug is withdrawn than when it is persistently taken. This mental state may show itself as paranoia, with multiform hallucinations, or as a marked exaltation or depression.

Recognition of opiumism depends chiefly upon the cachexia, the presence of many scars from the use of the hypodermic needle, the small pin-point pupils, and frequent marked inertia and semi-stupor, in contrast to the excitement seen in alcoholism. The patient will usually deny his habit; his moral sense is blunted, and he will go to any lengths to indulge his pathological craving.

Cocainism.

This produces marked stimulation. The pulse is increased and the pupils dilated. The patient is active and talkative, often repeating his remarks. He is extremely busy at something, often something irrational. The effects are transitory and the dose has to be frequently repeated to maintain them.

There develops in chronic addicts a marked emaciation, anaemia, insomnia, various paresthesias, and sometimes epileptiform attacks. There is a lack of ability to concentrate the mind, irritability, impaired judgment, lessened moral sense, often a tendency to crime.

There is mendacity and irritability, and often delusions are developed, especially that of marital infidelity. Mental confusion and hallucinations may grow until they settle in a paranoid state, distinguishable from true paranoia chiefly by the variety and transitory nature of the delusions, those of paranoia being somewhat fixed and monotonous.

Symptoms arising from deprivation of the drug are less severe than those associated with morphine and may be delayed for a few days before appearing. The patient may then develop a depressed, lachrymose state, with persistent delusions of persecution.

Miscellaneous Poisons.

There are many poisons the persistent use of which develops psychoses. Among them are; chloral, ether, chloroform, antipyrin, phenactein, belladonna, quinine, and preparations of lead, mercury, arsenic, and the bromides. All are characterized by acute hallucinatory confusion.

PSYCHOSES OF UNKNOWN PATHOLOGY

Paranoia.

Paranoia is a chronic, progressive, mental disorder, characterized by systematic delusions of persecution, hallucinations of hearing, and little or no intellectual impairment.

It usually passes through three stages: A. The stage of **subjective analysis,** in which the patient worries about himself and develops delusions of relativity; that is, interprets everything in his environment as having to do with himself. Every casual act of an acquaintance, and often the acts of strangers, are believed to be directed at him or done on his account. B. The stage of **persecution,** which grows naturally upon the first stage. Systematized delusions of persecution occur and are bolstered up by falsification of memory, whereby the patient goes back into his experience and reconstructs events of the past, construing them so as to prove a bearing upon his delusion. There are often hallucinations of sound in this stage. C. The stage of **transformation of personality.** The patient develops exaggerated ideas of his own importance.

In some cases the stages are less clearly defined and grandiose ideas may characterize the case from the start. This is the **expansive form.** These cases may become great inventors, or religious reformers, and very well known. Extreme exaggeration of the ego together with more or less persistent delusions of persecution are the earmarks of the condition. The expansive paranoiac may grow long hair or adopt bizarre apparel to make himself conspicuous; may imagine himself a super-great man, the reincarnation of Christ or Buddha, or something of the sort; he may imagine that all those who reject his inventions or beliefs are enemies, seeking his death; and he may hear disembodied voices commanding him to action or reviling him.

The disease runs a long course. The presence of elaborately systematized delusions supported by logical argumentation, the absence of intellectual impairment, and the progressive course,

serve to establish the diagnosis, but paranoia must be differentiated from paranoid states caused by toxins.

Manio-Depressive Insanity.

A disease, occurring in repeated attacks with apparent recovery between them, and showing itself in two types; the **maniac stage** and the **depressive stage.** The maniac stage is made up of flight of ideas, psychomotor excitement, and emotional depression. The depressive stage consists of difficulty of thinking, psychomotor retardation, and emotional depression. There are several mixed stages, and in some cases there are periodical insanities, in which the maniac and depressive stages occur in varying relations and perhaps with lucid intervals. The commonest of these are:

Recurrent Mania.

Recurrent maniacal attacks separated by lucid intervals. Recurrent melancholia—repeated depressive attacks with lucid intervals between.

Circular Insanity.

Alternating maniacal and depressive attacks without lucid intervals.

Alternating Insanity.

Regularly alternating attacks of mania and depression, each attack followed by a period of lucidity.

Double Insanity.

Each attack consisting of a period of mania and one of depression, and each double attack followed by a lucid interval.

Dementia Praecox.

This is a psychosis of puberty and adolescence, characterized by a dementia which tends to progress, though frequently interrupted by remissions.

Usually begins with temporary confusion and depression. The symptoms thereafter are those of progressive dementia; failure of attention, lack of interest shown by the patient in himself and his surroundings, failure of memory, emotional deterioration, all without loss of orientation or clouding of consciousness.

There are four fairly well defined forms of dementia praecox.

Simple Dementia.

Usually begins with depression and shows delusions and hallucinations. There may be slight transitory excitement, and slight muscular tension, mannerisms, and peculiar habits. The early stage somewhat resembles melancholia and neurasthenia, from which it must be distinguished.

Hebephrenia.

Has a prodomal period of depression. The delusions and hallucinations are prominent and absurd. There is poverty of ideas and incoherence of thought.

Katatonia.

Has a rather slow onset during which epileptiform attacks and hysterical convulsions may occur. When the case is developed to the **katatonic stage** there are muscular tension and marked negativism. The latter may manifest itself in mutism and in retention of urine, faeces, and saliva. The patient may be well oriented. Some cases develop echolalia, echopraxia, and like symptoms. Later, there may develop **katatonic excitement,** in which the patient is very active, throwing himself about, shouting and talking. Incoherence and verbigeration are common.

There are, as well, paranoid forms of dementia, which show well-marked, systematized delusions and hallucinations, but with early evidences of mental deterioration of the dementia type.

Paresis.

This is a mental disorder of known pathology. It proceeds from inflammatory and degenerative disease of the brain, especially of the pia mater and cortex, and is characterized by a progressive mental deterioration together with certain physical symptoms.

First Period. Argyll-Robertson pupil, loss of consensual light reflex, loss of sympathetic light reflex. Abnormality of the patellar reflexes appear early. At the same time there are gradual alteration of character, failure of memory, inability to concentrate or to work continuously, lack of judgment, diminution of the sense of moral values. There may be slow, slurring, or stumbling speech, and writing may be similarly affected. There is tremor of the facial muscles.

Second Period. Apoplectiform and epileptiform seizures usher in this phase—the so-called paretic seizures. The mental symptoms progress to a marked deterioration and the physical symptoms are those of the first stage exaggerated. The mental symptoms now may take on one of several forms; the demented type, the agitated type, the expansive type, or the depressed type.

Third Period. In this stage the patient is bedridden; physical signs are all increased; and mental life is virtually extinct. The patient is filthy and animal-like in his habits.

Diagnosis. Abolition of knee-jerks and the appearance of the Argyll-Robertson pupil in a man of middle age, if locomotor ataxia can be eliminated, suggests the possibility of a beginning general paresis. Until signs of mental deterioration appear it is not wise to hazard a diagnosis. These signs, while they may not at first obtrude themselves, may be discovered if sought for. A change in personality, development of irritability, loss of memory, increasing slovenliness in personal appearance and uncertainty in the performance of familiar acts—a number of things, slight in themselves, which may, in the aggregate, reveal mental deterioration, make the diagnosis not too difficult.

There are, of course, several conditions which resemble paresis. First of these is perhaps acquired neurasthenia, although the progress of paresis into the second stage rules this out. Others are brain tumor, cerebral syphilis, alcoholism, arteriosclerotic insanity, and some of the psychoses.

A true paresis is probably always incurable.

Feeble-Mindedness.

Is a condition of slight mental defectiveness, either congenital or acquired, which is susceptible of considerable improvement by education. The truly feeble-minded child may be hard to educate, but can acquire enough education to take a place in society and perhaps be self-supporting.

Imbecility.

Is a more marked mental defectiveness than feeble-mindedness and less marked than idiocy. The mental condition of the imbecile can be somewhat improved by special training, but not enough to

take employment and occupy an independent place in the world. **Moral** imbecility is that in which the deficiency involves the moral sense to a much greater degree than other faculties. Such a case may be improved, but will always require surveillance and restraint to prevent danger to society.

Idiocy.

Is a profound mental defectiveness of a hopeless character. They differ according to cause; among common causes may be listed the following: Microcephalic cases; hydrocephalic; epileptic; paralytic; traumatic; eclampsia, sclerotic; syphilitic; encephalitic; cretinism; idiocy by deprivation.

VISCERAL INNERVATION

Heretofore in this book nerve structures have been discussed chiefly from a centrifugal viewpoint. The nerve parts, beginning with the central organs and proceeding outward to their connected peripheral nerves, have been described and their origin, functions, and abnormalities discussed but in these discussions the other organs of the human body have been mentioned only incidentally, and as they happen to be connected with, or related to nerves. This is proper enough in a textbook devoted avowedly to Neurology. Before concluding, however, it seems advisable to temporarily reverse the viewpoint and examine the nerve system using as a starting point the various important organs of the body—important, that is, especially in that they are frequently the sites of disease processes, and that their diseases are often dangerous to life and frequently the cause of the patient's visit to a doctor.

A large part of general practise is made up of visceral disease. Include disorders of the bronchi, lungs, heart, blood-vessels, stomach, intestines, liver, pancreas, kidneys and bladder, and reproductive organs, and add diseases of the endocrinous glands, such as the thyroid and the adrenals and the list will cover more than 90% of all practise.

Since the nerve tissue is the controlling tissue of the body which, by its reception of information at once as to the progress of every vital function and the condition of every organ, is enabled to send forth such impulses as will harmonize and co-ordinate all the multifarious activities which are necessary to perfect life, it follows that the nerve system is the prime factor in the maintenance of health and must frequently be deranged in order that disease may occur. It is known that most of the multitude of factors which act as causes of disease operate with greater or less effect upon the body according as its natural resistence is lowered or increased; and that the chief elements in the marshalling of the body resistence to adverse influences is the power of the nerve system to organize and command the body forces. It is apparent that from the standpoint of diagnosis and treatment it may often be vitally important to know, and to take into account, the precise nerve supply of the affected organ, its connections with the central nerve system, and the possible ways in which the nerve supply may be interfered with. No work on Neurology would be truly complete without such consideration.

Double or Multiple Innervation.

In a simply organized animal form, a single nerve trunk may pass from a nucleus or cell cluster within the central nerve system directly to the innervation of a single organ, the former having no other destination and the latter no other nerve supply. In more complex animal forms, organs have been formed by the fusing together of formerly separated elements; parts which have joined in the organization have, by changes in the functional needs of the organism and re-distribution of labor, become useless and as a consequence have disappeared, leaving as a part of the nerve supply of the organ with which they were formerly associated, their nerve connections. Organs have migrated from their earlier positions to situations sometimes very remote and in the migration have become united in new combinations with other parts; the nerves originally connected with a tissue follow it in its migrations, sometimes by progressive elongation of the nerve fibres and sometimes by drawing after them their cell bodies to form ganglia situated between the central nerve system and the peripheral termination of the nerves.

All these modifications serve to bring about, in the developed human body, a tendency for important organs to be connected each with more than a single set of nerves. That is to say, the nerves which supply an important organ are rarely all derived through the same trunk nerve and from the same segment within the central axis. Sometimes a number of widely separated segments are represented in the control of a single major organ, each pathway regulating a separate function of the organ or a separate part of its substance.

From the pathological standpoint not all these pathways are of equal importance. Some are less pervious to interference than others. Clinical experience enables us to select from among the two, three, or more nerve pathways to a given organ the one which is most often responsible for its sub-innervation and consequently its susceptibility to the influence of disease-producing factors.

In the succeeding pages we shall take up in turn the important organs, including some of the endocrinous glands, describe their complete nerve supply, and indicate that pathway which is most important in connection with each organ. No attempt will be made to describe the various pathological conditions which may arise in the organs, or their symptoms, subjects both of which belong

rather to textbooks on pathology and diagnosis than to the domain of Neurology.

The Brain.

Although itself the central organ of the nerve system, the brain is subject to the laws of growth, nutrition, and repair which apply to other living tissues. It has a rich blood supply, through the Circle of Willis and its branches, and depends upon this supply for its oxygen and nutritive materials, and for the elimination of waste matter. Many of the pathological processes which affect the brain are due primarily to some alteration in its blood-supply, or to some imperfect distribution of blood.

The blood vessels of the brain are well supplied with vaso-motor nerve fibres, most of which accompany the carotid arteries and their branches; these are derived from the superior cervical ganglion, situated in front of the transverse processes of the second, third, and fourth cervical vertebrae. This ganglion is connected to the upper four cervical spinal nerves only by gray rami communicantes, but is the terminus for white fibres derived from the upper thoracic spinal nerves and ascending in the sympathetic trunk. Vaso-motor centers in the spinal cord, especially in the cervical and upper thoracic segments, give origin to the preganglionic fibres in this pathway for vaso-motor control of the blood supply to the brain.

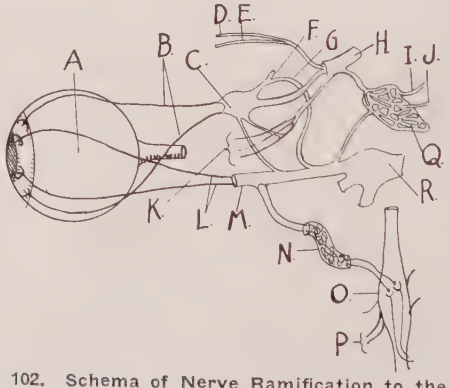

Fig. 102. Schema of Nerve Ramification to the Eye. A, Eye; B, To Sphincter Pupillae; C, Ciliary Ganglion; D, To Levator Palpabrae; E, To Rectus Superior; F, Sympathetic Root of Ciliary Ganglion; G, Naso-Ciliary Nerve; H, Oculomotor n.; I, Trochlear n.; J, Abducent n.; K, To Recti; L, To Dilatator Pupillae; M, Ophthalmic n.; N, Carotid Plexus; O, Superior Cervical Ganglion; P, Superior Cardiac Nerve; Q, Cavernous Plexus; R, Gasserian Ganglion.

The Eye.

The motor nerves of the eye are the oculomotor, trochlear, and abducens. The general sensory nerve is the trigeminal, by

its opthalmic branch. The special sense nerve of vision is the optic nerve. All of these connect directly with the cerebrum. Their trunks and branches, however, are richly supplied with sympathetic fibres derived from the superior cervical ganglion by way of the internal carotid nerve and the carotid and cavernous plexuses. The condition and carrying capacity of these nerves of the eye are determined to a great extent by their structural integrity, which depends upon normal nutrition and blood-supply, controlled by the sympathetic. Dilator fibres for the iris descend the spinal cord to the upper thoracic segments, emerge with the white rami, ascend to the superior cervical ganglion and there end in relation to the cells from which new (*postganglionic*) neurons complete the pathway to the eye.

The Nose.

The special sense nerve of smell is the olfactory nerve, or first cranial nerve. Its connection is directly with the under surface of the cerebrum which it reaches by numerous strands through the apertures in the lamina cribrosa of the ethmoid. The ganglion cells of origin of this nerve lie in the mucous membrane lining the upper part of the nose. The general sense nerve to the nose is the trigeminal; the motor nerve to its muscles, the facial. The secretion of the glands of the nose and the vascular supply on which its nutrition depends, and consequently the nutrition of the olfactory nerve cells as well, is controlled by the sympathetic, from the superior cervical ganglion by way of the sphenopalatine ganglion.

The Ear.

The ear contains the special end-organs in which the two divisions of the eighth cranial nerve, the acoustic nerve and the vestibular nerve, terminate. The former is the special sense nerve of hearing, the latter that of equilibrium. The structures of the ear are supplied by the auricular branch of the vagus, the auriculo-temporal branch of the trigeminal, the tympanic branch of the glossopharyngeal (*Jacobson's nerve*) and branches from the carotid plexus. All except the latter connect directly with the cerebrum; the carotid plexus derives from the superior cervical ganglion and its branches to the ear control the blood-supply.

The Pharynx.

The pharynx is supplied by the pharyngeal plexus of nerves, made up of sensory fibres from the vagus and glossopharyngeal,

motor fibres from the vagus, and secretory and vaso-motor fibres from the superior cervical ganglion.

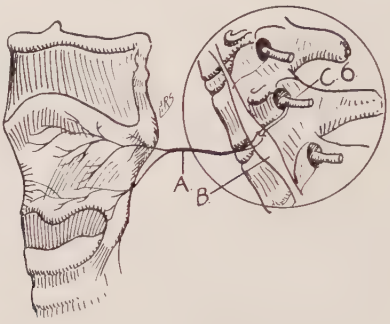

Fig. 103. Nerve Supply to Larynx.
A, Postganglionic Fibres; B, Inferior Cervical Ganglion; C, Sixth Cervical Nerve.

The Larynx.

The larynx is innervated by a sensory branch, the superior laryngeal and a motor branch, the inferior or recurrent laryngeal, from the vagus, and by sympathetic vaso-motor and secretory fibres chiefly from the middle cervical ganglion. This latter pathway is the one by which the nutritions of the larynx is maintained.

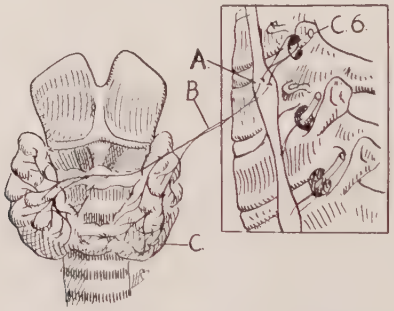

Fig. 104. Nerve Supply to Thyroid Gland.
A, Middle Cervical Ganglion; B, Postganglionic Fibres from Middle Cervical Ganglion; C, Thyroid Gland; C6, Sixth Cervical n.

Thyroid Gland.

While the inferior laryngeal branch of the vagus sends a small branch to the thyroid, its function is really presided over by sympathetic filaments derived from the middle cervical ganglion situated in front of the transverse process of the sixth cervical vertebra, and from the sympathetic trunk between that ganglion and the inferior cervical ganglion. Secretory and vaso-motor fibres follow this pathway.

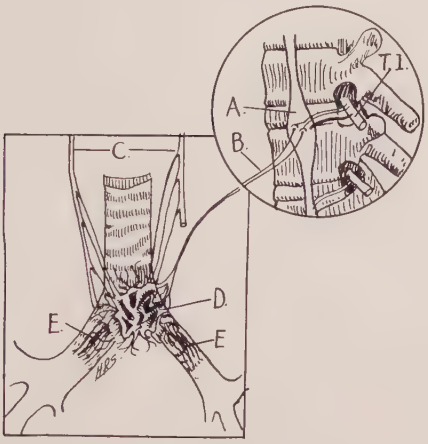

Fig. 105. Innervation of the Bronchi.
A, Thoracic Ganglion; B, Postganglionic Fibres to Cardiac Plexus; C, Vagus Nerve; D, Cardiac Plexus; E, Fibres from Cardiac to Pulmonary Plexus.

Bronchi.

The bronchi derive their nerve supply from the vagus and from the pulmonary plexus, made up of a mingling of vagal fibres with fibres from the second and third thoracic ganglia of the sympathetic. These latter in turn receive white rami from the first and second thoracic spinal nerves, so that the source of impulses to the bronchi may be traced back into the upper thoracic segments of the spinal cord. In inflammatory bronchial conditions especially, the spinal connection is important.

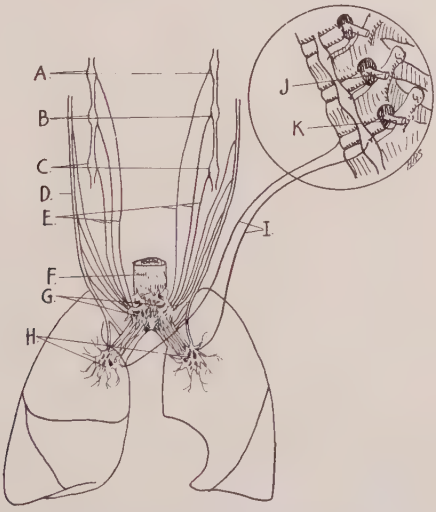

Fig. 106. Nerve Supply to the Lungs.
A, B, C, Superior, Middle, and Inferior Cervical Ganglia; D, Left Vagus Nerve; E, Cardiac Nerves; F, Trachea; G, Deep Cardiac Plexus; H, Pulmonary Plexus; I, Postganglionic Fibres from Third Thoracic Ganglion to Pulmonary Plexus; J, Second Thoracic Nerve; K, Third Thoracic Nerve.

The Lungs.

The nerves to the lungs are the vagus and the sympathetic, the latter traceable to the second and third thoracic ganglia and through the white rami entering these ganglia to the upper thoracic cord segments. Vaso-motor centers for the lungs seem to be located in the lower cervical cord, slightly above the points of emergence of the spinal nerves which give off white rami to the lung pathway. The third thoracic nerve is the most important.

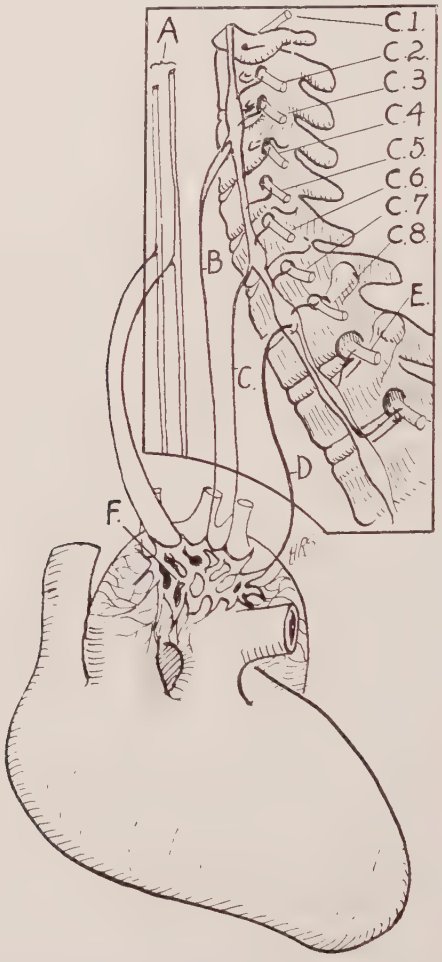

Fig. 107. Nerve Supply to the Heart.
A, Vagus Nerve; B, Superior Cardiac n.; C, Middle Cardiac n.; D, Inferior Cardiac n.; E, Second Thoracic n.; F, Cardiac Plexus.

The Heart.

The immediate nerve supply to the heart muscle arises in the coronary plexuses and in the intrinsic ganglia of the heart itself.

These in turn are supplied from the cardiac plexus, which lies at the base of the heart. It is made up of branches from the right and left vagus and from the three pairs of cervical cardiac nerves, which descend from the superior, middle, and inferior cervical ganglia. These cardiac nerves are postganglionic; their related preganglionic fibres leave the spinal cord as white rami communicantes with the first and second, particularly the second thoracic nerves, ascend through the stellate ganglion and terminate in one or the other of the three cervical ganglia.

The function of the vagus is to inhibit the muscular action of the heart; that of the sympathetic pathway to accelerate action; the two are mutually antagonistic and regulatory. Both trace back to different parts of the cardiac center in the medulla, one part of which is cardio-inhibitor and the other cardio-accelerator. While theoretically interruption or interference with either pathway would modify the action and eventually the condition of the heart, in practise the vagus is so situated as to be almost immune from physical interference and the accelerator pathway is usually the one at fault.

Diaphragm.

The diaphragm, a muscle rather than a viscus, is included here because of its relation to the vital function of respiration. It is innervated by three pathways. The phrenic nerve arises from the fourth, fifth, and sixth cervical nerves, descends through the thorax and spreads out in a leash of branches to the diaphragm as its motor nerve. Lower intercostals supply the margins of the diaphragm near its attachment to the thoracic wall. The phrenic plexus of the sympathetic, derived from the coeliac, controls the blood-supply to the diaphragm. This latter connects with preganglionic fibres which probably emerge from the spinal cord with the fourth and fifth thoracic nerves. The principal pathway, however, is that from the fourth cervical nerve by the phrenic.

Stomach.

The direct innervation of the stomach is by way of Auerbach's and Meissner's plexuses, lying between the layers of muscle and immediately beneath the submucous coat. These plexuses are formed by a mingling of branches from the vagus and from the coeliac plexus, whence they are derived by way of the great splanchnic nerves, from the fifth, sixth, seventh, and eighth thoracic nerves, more especially the sixth. Motor impulses reach the stomach chiefly

by the vagus but to some extent by the splanchnic pathway; secretory and vaso-motor impulses by the splanchnic—coeliac plexus pathway, which is clinically the more important.

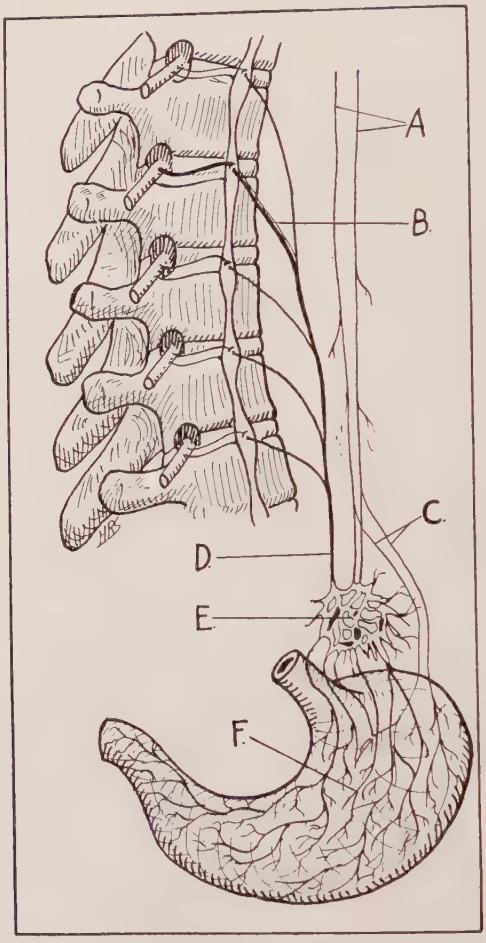

Fig. 108. Schema of Nerves to the Stomach. A, Vagus Nerves; B, Postganglionic Fibres from T6; C, Direct Fibres from Vagus to Stomach; D, Great Splanchnic Nerve; E, Coeliac Plexus; F, Stomach.

Liver.

The nerve supply to the liver is by way of the vagus, especially the right vagus, the right phrenic nerve, and subplexuses from the coeliac. Trophic, vaso-motor, and secretory fibres are derived through the coeliac plexus and numerous experiments have demonstrated that their preganglionic fibres emerge from the spinal cord in the thoracic region. Various investigators have localized these efferent preganglionic fibres to the liver all the way from T3

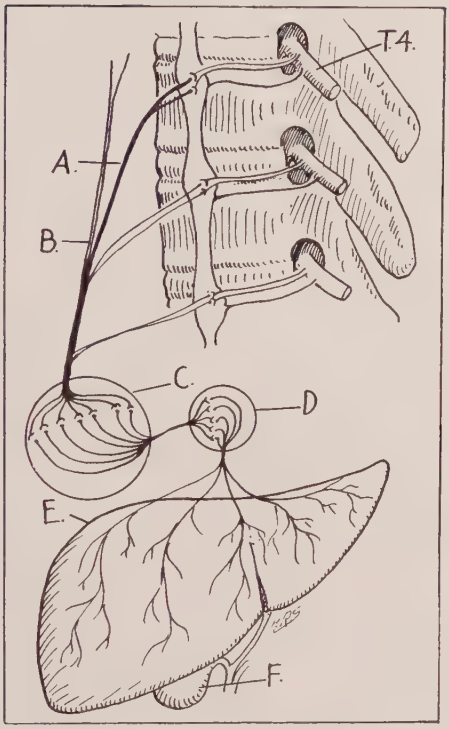

Fig. 109. Schema of Nerve Ramification to the Liver.
AA, Great Splanchnic Nerve; B, Vagus; C, Coeliac Plexus;
D, Hepatic Plexus; E, Liver; F, Gall Bladder.

to T11 inclusive. The majority opinion places them, or at least the most important of them, in T7 and 8. However, the clinical experience of this writer is at variance with common opinion. In an extended series of experiments, in which every precaution was taken to exclude cases of doubtful diagnosis, the **fourth** thoracic nerve (*right*) was found to be the important connection in every case save one; in that single case T6 was the effective pathway.

Gall-Bladder.

It is probable that many cases in which the gall-bladder alone is involved are mistaken for liver cases. The gall-bladder is innervated by the cystic plexus, which derives motor fibres from the vagus and inhibitor fibres from the eighth and ninth thoracic nerves by way of the great splanchnic and the coeliac plexus.

Pancreas.

The nerve supply to the pancreas is arranged in the form of plexuses which follow the arteries; the splenic, hepatic, and

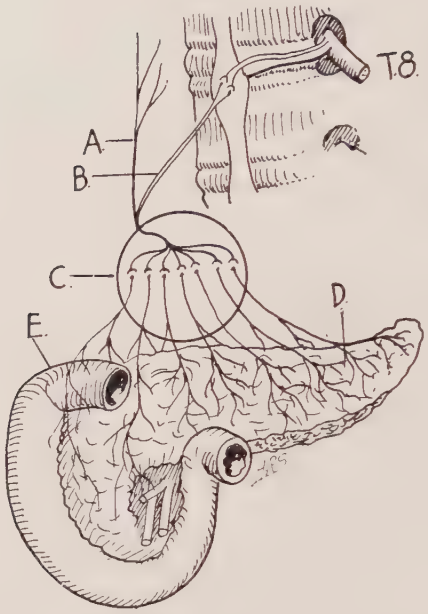

Fig. 110. Nerve Distribution to the Pancreas.
A, Greater Splanchnic Nerve; B, Post-ganglionic Fibres from T8; C, Coeliac Plexus; D, Pancreas; E, Duodenum.

superior mesenteric. These plexuses derive from the coeliac and are made up of vaso-motor and secretory fibres from the vagus and splanchnic. The latter are continuations of pathways of which the preganglionic fibres emerge mostly by the eighth thoracic nerve. This is the most important connection with the pancreas.

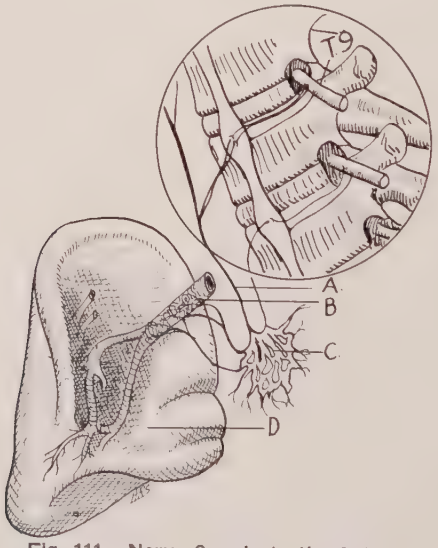

Fig. 111. Nerve Supply to the Spleen.
A, Greater Splanchnic Nerve; B, Splenic Plexus; C, Coeliac Plexus; D, Spleen.

Spleen.

The spleen is innervated by the splenic plexus, an offshoot of the coeliac; the splenic plexus follows the artery into the hilum of the spleen and carries vaso-motor fibres principally. Some of these fibres may be derived from the vagus, but most of them can be traced back to the thoracic nerves. Some physiologists aver that the important spinal connections are with the sixth, seventh, and eighth thoracic nerves. This writer's investigations place the important pathway slightly lower—in the **ninth** thoracic.

Small Intestine.

The innervation of the small intestine is by way of the eighth, ninth, and tenth thoracic nerves, through the splanchnics and the coeliac plexus, to subplexuses located in the intestinal walls. These fibres are vaso-motor, secretory, motor, and sensory. Motor fibres apparently pass also by way of the vagus, but these are of less practical importance than the splanchnic pathway.

Large Intestine.

The large intestine, being made up of the fusation of a number of primitive segments, has a fairly extensive connection with the central nerve system, extending from about the tenth thoracic through the sacral region. The important pathways to the **vermiform appendix** are by way of the tenth thoracic and splanchnic nerves (*lesser*) and through the coeliac and superior mesenteric plexuses, and from the second lumbar nerve by way of the sympathetic cord

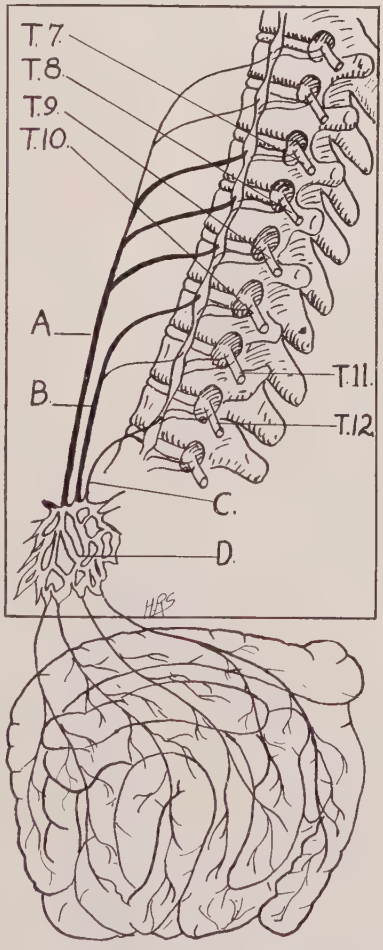

Fig. 112. Nerve Supply to Small Intestines.
A, Greater Splanchnic n.; B, Lesser Splanchnic n.; C, Least Splanchnic n.; D, Coeliac Plexus.

and the inferior mesenteric plexus. The rectum is connected with the last two lumbar nerves and the sacral. The remainder of the large intestine derives preganglionic fibres from the upper three lumbar nerves principally.

Kidneys.

The renal plexus supplies the kidneys. It follows the renal artery, carrying motor, sensory, vaso-motor, and secretory fibres. The preganglionic fibres are derived from the tenth, eleventh, and twelfth thoracic nerves. They travel by the lesser and least splanchnic nerves to the abdominal aortic plexus and the aorticorenal ganglion. The latter ganglion gives off some of the postganglionic fibres to the kidney, while others derive from the lower thoracic ganglia of the sympathetic trunk, and from collateral ganglia situated in the renal plexus and in the kidney itself.

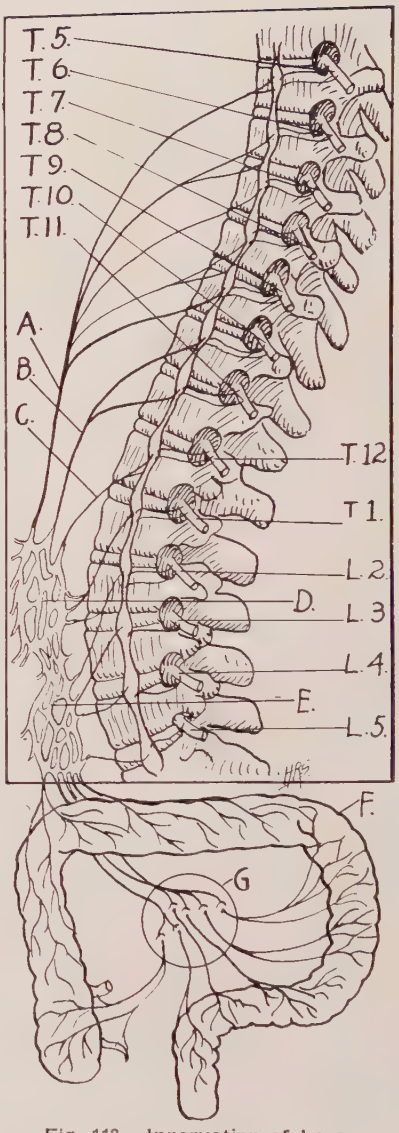

Fig. 113. Innervation of Large Intestines.

A, Greater Splanchnic n.; B, Lesser Splanchnic n.; C, Least Splanchnic n.; D, Coeliac Plexus; E, Inferior Mesenteric Plexus; F, Colon; G, Hypogastric Plexus.

Bladder.

The urinary bladder is supplied with nerves from the second, third, and fourth sacral nerves and from the hypogastric plexus. The sacral branches are the "visceral branches" which pass directly to the bladder; those from the hypogastric plexus are postganglionic fibres; their preganglionic connections are with the lower lumbar ganglia of the sympathetic and thence with the upper lumbar nerves.

Suprarenal Capsules.

These important endocrinous glands are supplied with nerves by the suprarenal plexus, which derives from the

Fig. 114. Nerve Supply to the Kidney. A, Greater Splanchnic Nerve; B, Lesser Splanchnic Nerve; C, Coeliac Ganglion; D, Least Splanchnic Nerve; E, Aortico-Renal Ganglion; F, Renal Plexus; G, Coeliac Plexus.

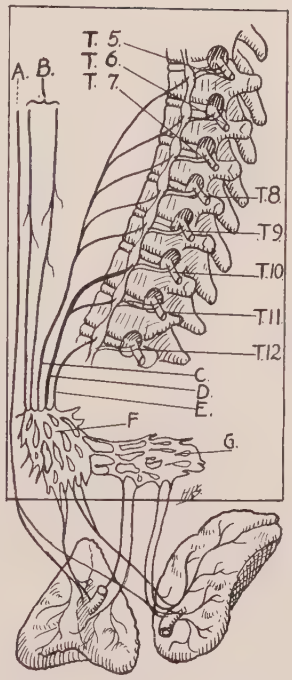

Fig. 115. Nerve Supply to Suprarenal Capsules.

A, Phrenic n.; B, Vagus Nerves; C, Greater Splanchnic n.; E, Lesser Splanchnic n.; E, Least Splanchnic n.; F, Coeliac Plexus; G, Renal Plexus.

coeliac and renal plexus, and carries some filaments from the vagus, phrenic, and splanchnic nerves. The plexus is very rich, follows the blood-vessels into the capsules, is made up of fine medullated fibres chiefly, and has many small ganglia on its branches. The spinal connection of the suprarenal plexus is with the tenth thoracic nerve principally, less frequently with the ninth and eleventh.

Ovaries.

The nerve supply to the ovaries is double. One pathway is by way of the tenth and eleventh thoracic nerves, through the lesser splanchnic nerve, the coeliac and renal plexuses, and the ovarian plexus. The other is by way of the second and third lumbar nerves, through the lumbar ganglia, the hypogastric plexus, and the uterine plexus. The nerve connections with the **testes** in the male

are analagous to the above, the spermatic plexus taking the place of the ovarian.

Uterus.

The innervation of the uterus is by way of the third, fourth, and fifth lumbar nerves to the inferior mesenteric ganglia, and by the hypogastric plexus to the uterus. There is also a direct pathway to the lower part of the uterus through the second, third, and fourth sacral nerves.

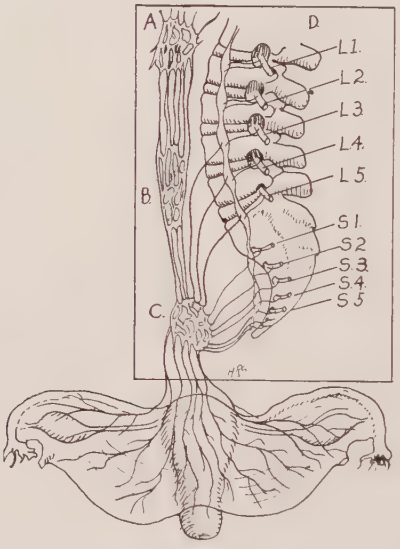

Fig. 116. Nerve Supply to Uterus. A, Coeliac Plexus; B, Hypogastric Plexus; C, Pelvic Plexuses; D, Lesser Splanchnic Nerve.

THE PHILOSOPHY OF NERVE ACTION

Philosophy. The knowledge of phenomena as explained by, and resolved into, causes and reasons, powers and laws.—Webster.

The facts which have been ascertained concerning the actions which take place in and through nerves are not all readily susceptible of explanation. As yet no adequate means has been found for studying the nerve impulse itself; only its manifestations in the form of effects upon the tissue through which it operates and the other tissues of the animal body can be observed. Reasoning upon these phenomena has been difficult because they are so multiform and varied; because experiment upon living subjects is likely to include some departure from normal conditions which will modify the resultant phenomena; because experimentation upon the cadaver, while it discloses the anatomical arrangement of nerves, cannot in the nature of things disclose anything about the action of living nerves.

Physiologists, performing the same series of investigations, frequently produce varying results and arrive at different conclusions therefrom. Only a comparatively few phenomena of nerves can be demonstrated sufficiently often and with sufficient exactitude of repetition to justify the statement of positive laws. The outstanding characteristic of nerve phenomena is their mutability.

The weight of opinion upon many questions touching the theory of nerve action changes from decade to decade, even from year to year. Doubtless within the next generation it will be necessary to revise, in the light of additional information gathered by—perhaps —new methods of research, many of the beliefs and theories now justifiably entertained.

It is advisable, nevertheless, in order that practical use may be made of the fairly impressive mass of knowledge already gained on the subject, that the student of neurology should formulate a set of basic beliefs, consistent with each other, and sufficient to explain all nerve activities which are explainable at all. Such a set of opinions will, of course, be subject to revision as new evidence is adduced which alters the total weight of evidence. It will, of course, leave

an unexplored and hazy borderland beyond the limits of present knowledge and extending into the mystery of Life and Creation.

The student of neurology who pursues his research and his meditations to the uttermost possible horizon finds himself somewhat encroaching upon the domain of the metaphysician. It is at this margin of encroachment that this writer purposes to stop, believing that for practical utility every theory should be at least linked with provable, demonstrable facts, the kind of facts which can be observed in the clinic or produced in the laboratory.

With this preliminary statement of purpose we shall proceed to discuss, under various subheads, those nerve phenomena concerning which it seems possible to explain causes and reasons, powers and laws.

Relation of Philosophy to Physiology.

Nervous physiology is the study of the functions of nerve tissue; of that function common to all nerve tissue, the generation and conveyance of nerve energy; and of the special functions of particular nerve organs, which functions are, in fact, determined by the nature and characteristic action of the organ supplied by the nerve rather than by any special structure of the nerve itself.

The study of such functions is inseparably linked with consideration of the reasons for them and the laws that govern them. A clear understanding of any physiologic fact demands that an explanation be coupled with the fact. It follows, therefore, that the study of the philosophy of nerve action is intertwined with nervous physiology and never entirely separable from it. In the section devoted to Nervous Physiology (pp. 234 to 369) much has been said which will be restated.

Life Force.

The chief characteristic of living bioplasm by which it is distinguishable from inanimate substance is its ability to act upon and react to its environment. It possesses irritability, motion, and the power to repair and reproduce itself. Vegetable substances manifest a kind of life; they are usually limited in the power of motion and possess a very low grade of irritability but reproduce their kind readily.

The unit of all organisms, whether vegetable or animal, is the individual cell. Aggregations of cells of like, or related, kind, work-

ing together for the accomplishment of some common function, constitute an organ; aggregations of organs, performing by their co-operation, some systemic function, make up a system; organs and systems may be aggregated to form a vegetable or an animal body.

With vegetable bodies we are little concerned except to recognize in them evidences of a kind of life, indeed two kinds of life, for there is not only the individual cell life but the life of the plant as a whole, dependent upon the continued life of a sufficient number of its component cell elements.

Animal life differs from vegetable life in its degree of motility, the rapidity of its metabolism, and its ability to respond to stimuli from outside itself. The unit of animal existence, as in the vegetable world, is the life of the single cell. There exists a multitude of living organisms made up of only a single cell each, or a few cells united to each other. As organization of animal cells proceeds and increases in complexity, the life of the entire organism depends upon the continued life of most of its cells and the maintenance of cell life in turn depends upon the continuance of co-operation between the parts of the entire organism. The organs which have developed the special function of ingestion, or food-getting, must provide nourishment for the use of all the cells; those devoted to digestion must prepare this food for use; those engaged in circulation must carry the food to the cells; and those whose function is respiration must provide oxygen for combustion.

We perceive two forms or planes of life; **cell** life and **somatic** life, in each animal body. Each is dependent upon the other for its perpetuation. Is somatic life, then, merely the sum-total of the aggregate cell lives within it? Manifestly not. Cell life may, and often does, persist in parts of an animal body after somatic life has departed. Somatic life appears to be the organizing force which links the cells together in co-operation and directs their activities. Hereafter, in referring to life, we shall mean somatic life—the life of an individual animal, or, better still, human life, which manifests all the characteristics of other grades of animal life and adds to them certain reactions and processes which we call **psychic**, belonging to the realm of intelligence.

Life force is not merely a product of the physical and chemical forces working within the body. Life is undoubtedly a form of energy—imponderable—not measurable by material standards. Life itself eludes all our senses and all laboratory investigations. It is

known to us entirely by its expressions—by the manner in which it causes cells and tissues to act.

The expressions of life force vary from those finer and less physical manifestations which are called thought, through different grades of molar action by which the body moves and reacts to its environment, down to the ultimate chemical changes by which the structure of the body is constantly renewed as it is used up. In all instances the life force expresses itself according to the nature and use of the organ through which it is expended. Life force acting in and upon certain cells of the brain becomes thought, reasoning, or perception; the same kind of life force expressed through a gland shows itself as the act of secretion, and as the formation of a particular kind of secreted substance according to the exact makeup of the cells of the special gland; life force acting through skeletal muscle appears as contraction of muscle and movement of parts. The expressions are infinitely varied but there is but one **life.**

Since Life is that energy which inhabits an individual organism and regulates the action of all its parts and controls all the physical and chemical energies used within it, and since each part of the organism must share in the flow of life not haphazardly and fortuitously but variably in accordance with functional needs, a **distributing mechanism** is necessary. This distributing mechanism must be of such a character as will permit of regulation of the amount of life energy admitted to any given tissue at a given time. It must, to be effective, operate through a central bureau by means of channels of communication which give it immediate command of every part of the body. At the same time it must be in constant receipt of full and complete information as to the execution of all its commands, the conditions surrounding the performance of the various organic functions, and the changes in the environment which necessitate changes in the activity of some organs to adapt them to external alterations. There must, in other words, be a central station linked by both efferent and afferent pathways with every tissue and cell group of the body whose activities are to be co-ordinated.

Such a mechanism is the nerve system. Its central organ is somewhat spread out, extending as it does through the brain and the spinal cord and out into the sympathetic ganglia, which are really detached and migrated portions of the central axis. These central organs are complicated by the presence within them of a multitude of communicating pathways for mutual exchange of information between parts. The complexity of the nerve system as a whole has

been increased to such a degree that it is at first difficult to perceive in it the principle of its arrangement. Studied analytically, however, the nerve system is seen to be arranged as a communicating substance between life and the body. In it the first and primary manifestations of Life occur. Through it, all Life passes before reaching or influencing anything else. The nerve system is, therefore, the direct agent of Life.

Because, under the influence of Life, nerve cells generate impulses of energy, which pass out over nerve fibres and, when expressed in peripheral tissue, produce evidences of Life; and because the nature of somatic life is unknown except as it acts through nerve tissue; and because it is more natural and less confusing to begin the study of the phenomena of life at the point where they produce changes in living tissue, it is convenient and defensible to apply the term "nerve energy" to that force which constantly flows through the nerve system as a primary manifestation of life. The term "nerve energy" is less broad than "Life" because it does not, strictly speaking, include that cell life which occurs without the intervention of a nerve system, in some of the simpler animal forms. It is more definite in that it is limited to those expressions of life which occur while the body is animated and takes no account of the possible continued existence of Life after its departure from the physical body. It omits also those forms of life which appear in vegetable organisms without distinct nerve systems. It is a workable term. Hereafter we shall refer to "nerve energy" or "nerve force" in the above described sense of its meaning.

Nerve energy is a high and perfect manifestation of intelligence, the highest and most perfect that we humans know. It is the most intimate expression of the Creative Force recognizable by us and eludes our own powers of creation or comprehension.

The Nerve Impulse.

Nerve energy travels through the nerve system along definite and specific channels. This statement may be considered as open to question, inasmuch as under certain circumstances, nerve impulses seem to be diverted from their ordinary pathways and transferred to other paths. An example of this occurs in hemiplegia due to a lesion interrupting the cerebrospinal fasciculus of one side; voluntary motion on the affected side is at first completely interrupted, but afterward may be partially restored through the "secondary motor tracts," the rubrospinal, tectospinal,

etc. The fact probably is that these secondary tracts do not under such circumstances acquire and convey impulses which they could not convey at any time, but that when the influence of the cerebrospinal fasciculus upon the lower neuron cells is removed the impulses travelling by way of the secondary fasciculi become more potent in their influence upon the lower neurons. Association pathways between the cerebral cortex and the cerebellum, and between the cortex and the basal ganglia, are always present, but their activity becomes more important when ordinary channels are blocked. Likewise, the cortical control of the voluntary muscles is double, that is, bilateral; but one side only exercises this control under normal conditions; i. e., the left side of the cortex in right-handed persons. When the influence of the one side is blocked, the other side tends gradually to assume control of both halves of the body; it requires a process of education to fit it for the task, and evidences of such control are slow in developing; the control never becomes so complete as if the lesion did not exist; nevertheless, there is a resumption of some degree of voluntary control in cases in which the lesion persists.

Some investigators hold that in an early period of embryonic development the neurons are not separate and distinct from each other, but form a syncitium around the neural tube, through which nerve impulses pass in any direction without obstruction—radiate, as it were, in any direction. There is much doubt as to the soundness of this opinion. On the contrary there is much reason to accept the opposite view, that each neuron is from its very beginning a separate cell unit and that impulses pass from one neuron to another only at points where terminals communicate by contact.

Generation of Impulses.

The nerve impulse is generated within the nerve cell by a process the exact nature of which is unknown. It is known that the property of irritability possessed by nerve cells is such that they tend to respond to stimuli acting upon them by generating nerve impulses, which are then emitted over the axons projecting from the cells. When two or more stimuli reach a nerve cell from different sources, the cell seems to have the power of responding to one and neglecting the other. This power also has been questioned; there are those who believe that the response of the nerve cell is invariably, and unescapably, to the stronger of the arriving stimuli.

Against this view it is urged that at times nerve cells all through the system, but more especially in the brain, display a faculty for **retarding** or delaying response to stimuli. Stored-up memories are made up in large part of afferent impressions to which response has been delayed. The preponderance of evidence shows that while a great majority of all nerve impulses are generated in such direct response to peripheral stimuli as to appear almost automatic reactions, there resides in the nerve cell an inherent power to select, accelerate, or delay its response.

This belief implies the existence of a power of choice in the nervous system, or in the Mind. It is a declaration for the doctrine of Freedom of the Will. It conceives Man as not solely a creature of his environment, but as a being possessing power to select his environment and to govern his reactions to it, and therefore responsible for his actions.

Nature of the Nerve Impulse.

Because a change of electrical potential accompanies the passage of a nerve impulse through the nerve fibre, it has sometimes been assumed that the nerve impulse is of an electrical nature. Its rate of transit at once negatives this assumption; nerve impulses travel at the comparatively slow rate of from a few meters to fifty meters a second. A probable explanation of the change in potential which progresses along an axon with the nerve stimulus is that some elusive chemical change accompanies the transit and is responsible for the electrical phenomena.

Nerve impulses normally follow each other through the nerve fibre to the number of 8 to 12 per second. That is, nerve energy does not travel in a continuous current but in a succession of waves, each inducing a separate response or expression in the tissue to which it is given off. These waves do not make any visible or appreciable change in the axon as they pass through. They are not accompanied by rapid chemical changes, as shown by the fact that the chemistry of a nerve does not vary discoverably with increase or diminution of the stimulation of the nerve. There is, of course, a constant metabolism which maintains the structural integrity of the neuron, the nutrition of the processes being presided over by the cell body; but this process does not seem to be altered, either accelerated or retarded, by the passage of impulses over the nerve. It is safe to conclude then that nerve impulses are not chemical in character. No changes of temperature occur in an irritated nerve. Exception

to this is noted in cases of neuritis, inflammation of a nerve, in which vaso-motor nerves are so affected as to produce vascular engorgement along a nerve trunk, and resultant inflammation; this is not due to irritation of the nerve trunk itself but to irritation of its vaso-motor "feeders."

Apparently the nerve impulse is a molecular agitation—an agitation which would radiate, wave-like, were it not limited to the neuroplasm in the center of the nerve fibre. Its direction of travel depends upon its point of incidence and the presence of natural channels for its conveyance. Thus in the case of the afferent nerves, stimulated at the periphery through special receptive end-organs, the impression passes **toward** the nerve cell; when it reaches the cell, in spinal or cranial nerve ganglion, it there excites the cell to the production of a new impulse which is emitted centralward along the axon of the cell. A stimulus, or impulse, arising in a motor cell of the ventral horn of the cord passes toward the periphery because in that direction lies the axon of that cell, the natural channel for the outlet of its stimuli.

There is no reason to believe that an axon or a dendrite would not, if reversed in direction and a healthy union with the cell re-established, convey impulses as before, away from, or toward the cell. The precise distribution of the nerve impulses depends upon the structural arrangement of the nerve tissue.

Reciprocal Alteration of Structure.

The above statement may suggest that if structure dominates nerve function some of our other conclusions are unsound. It should be pointed out that the structure of the nerve system has undergone a slow but persistent modification through many ages of development, and that this modification has kept pace with functional needs. Changes in the functional requirements due to changes in the environment are followed by gradual adaptation of the nerve structure. This adaptation in turn prepares the organism for the acquisition of new and wider experiences from the environment and consequent further alteration of nerve structure. The development of nerve structure and nerve function has been mutual and reciprocal. It is quite as correct to state that nerve structure depends upon function as to reverse the statement. Both are true, and fundamental. Man is a combination of the material and the immaterial; each complements the other; neither is effective without its complement.

Relation of Nerve Energy to Organic Function.

Nerve energy is the exciting factor in all organic functions. Careful study of most, though not all, the functions performed by the various members of the body discloses their neurogenic origin and control. It can be demonstrated that the chemical and physical actions which go to make up the special function of an organ are initiated, directed, regulated, and at the proper time checked, by the arrival and expenditure of nerve impulses; and that as a rule these nerve impulses are generated in response to stimuli reaching the nerve centers over afferent pathways.

Those organic functions which relate the body to its environment, such as contractions of the various skeletal muscles, are of a voluntary character but none the less conditioned to a degree upon information reaching the brain through sensory nerve channels. Thus, mental awareness of increased resistance results in an augmentation of the nerve stimuli, causing an increased muscular contraction sufficient to meet or overcome the resistance. Such simple acts as the lifting of food to the mouth require for their perfect performance a continuous consciousness of the position of the hand and arm, the relation of the spoon or other implement to the hand, etc.

Those functions by which the body is nourished and maintained in a live and healthy state, the actions of the internal, involuntary organs, are maintained by means of reflex nervous action. In this case the afferent stimuli reach the ganglia or the spinal cord centers (*or analagous lower centers in the brain*) and excite responsive action of the nerve cells through which efferent stimuli are sent to the periphery to cause the characteristic action of the stimulated organ.

As suggested above, in most cases the precise nature of the nerve influence can be demonstrated and the exact pathway of nerve control determined. A few instances serve to throw doubt upon the universality of this law. The action of the heart muscle, which may be induced to contract after all its nerve connections are severed, has been considered by many physiologists as proof that activity arising entirely within a muscle, and generated by purely intramuscular causes, may occur. Around this contention a long controversy has been waged. In behalf of the neurogenic theory of cardiac action it is urged that even though all outside nerve connections be removed there remain within the substance of the heart itself small

sympathetic ganglia which are the immediate source of the normal heart stimuli, and which may continue to function for some time after disconnection with the central nerve system. They may, in fact, continue to function until they undergo cellular death by metabolic deterioration. This phenomenon of the continued cellular life of a part after somatic death is by no means confined to the heart. It occurs in other organs, especially in poikilothermous animals; human hair continues to grow after somatic death, proving the continuation of cell life in the hair follicles. This does not invalidate the fact that under physiologic conditions all bodily functions are of neurogenic origin.

The ability of any tissue to take up nourishment from the surrounding blood and lymph, combine it with the substances of the cell to renew living tissue, and discharge into the circulatory channels the waste products of such metabolism, is controlled by the nerves. Here occurs the ultimate change from inert matter to living bioplasm—the essential miracle of animal life; it is regulated by the nerves, all of which exert a trophic influence over the cells to which they are distributed.

One Type of Nerve Energy.

From the multiplicity of organic functions which are executed in consequence of the arrival of nerve stimuli it has been argued that the nerve impulses vary in character, and that there is a special vibratory rate, or a special amplitude of nerve wave, or a special quality or character of some other kind, which gives to each nerve impulse a discriminatory and pre-calculated effect upon its responsive organ. There is no evidence to support such a contention. On the other hand, experiment makes it plain that any nerve impulse, discharged in any organ, will, if of sufficient intensity, excite the action of that organ according to the cellular structure and natural habit of the organ. That is, any nerve stimulus expressed in a muscle can result only in contraction of that muscle and in its metabolism. If it does not produce these effects it evolves nothing at all. The muscle is so constructed as to respond in only one way to stimuli of any kind; under normal conditions it receives only physiologic stimuli, through nerves, and no other kind; but when, experimentally, the muscle is stimulated by an electrical current, or by irritant chemicals, or by mechanical or thermic means, its response is similar to that which arises from the nerve impulse. Varying the character of the stimulus to an organ does not alter the nature of the response.

Variations in the **intensity** of stimuli do alter the intensity of the response within certain limits, the limits of capability of the organ. Variations in the **frequency** of the stimuli have an effect similar to variations in intensity.

Channels Determining Factors.

What, then, is the determining factor which enables the nerve system to exercise control over the other tissues? Apparently it lies in the ability to select the **channel**, or **pathway**, which shall be called into activity. Once a nerve impulse is propagated by a cell and propelled into the axon, it will travel to the end of that axon and there will affect whatever cells be connected with that end, insofar as they are at the moment capable of responding to such a stimulus. The regulation occurs in the cell bodies rather than in their processes.

In the nerve cells resides power either to respond at once to a stimulus received from the periphery or from another nerve cell, or to delay such response for a time, or to refuse altogether to respond; also the power to react over one of several possible pathways to the exclusion of others with which it may be connected.

In the peripheral nerve trunks, except in the ganglia, there is no intercommunication between neurons. In the ganglia, and more especially in the central nerve system, neurons communicate with each other by the contact of end-tufts or collaterals of the one with the dendrites of another. One neuron often distributes stimuli to several others by arborization with the dendrites of a group of adjacent cells; it may reach a number of neurons by means of collaterals given off at intervals along the course of the axon and possessing the same carrying power as the axon. Within the brain especially, but to a lesser extent in the cord, a cell may give off a projection fibre and at the same time an associative or commissural fibre. Thus it may be able to utilize information received either by sending out a command to some peripheral organ, or by influencing other nerve cells, or both.

The selectivity of the nerve cells as to which influence they will obey, and when, is the determining factor in the regulation of the body. They choose the channel which at the moment shall convey the stimulus, they discharge stimuli into that channel, and anatomic and physiologic relationship does the rest.

Definite Nerve Pathways.

It may be concluded from the above, and correctly concluded, that every organic function has a specific pathway for its nerve control. This is not to say that each organ is dependent upon a single nerve trunk or nucleus; on the contrary, nature has provided that each important organ has several nerve pathways, each devoted to a particular part of the organ or to the control of a special function. Thus the nerves which control the secretion of the stomach glands are different from those which excite its muscular contraction. Often the excito-motor and inhibito-motor fibres to an organ travel by different nerve trunks; the vaso-augmentor and vaso-inhibitor fibres by separate pathways. Some organs which are made of parts originally derived from parts of several embryonic somites still have several sets of nerves. But **each cell** has its specific nerve connection with the central nerve system.

Only One Nerve System.

Attempts are sometimes made to establish a separation between the cerebrospinal nerve system and the sympathetic. This separation is seen to be unfounded when we discover that in the embryo they develop together; that the sympathetic ganglia are simply cell groups which have migrated outward from the neural crest, trailing behind them filaments of connection with the remaining cell groups which are never broken or lost. It is no more proper to consider the sympathetic a separate system because its cell groups are situated outside the vertebral column than to consider the spinal cord as apart from the brain because it does not lie within the cranial cavity.

There never has been more than a single nerve system in the individual animal. The older and more primitive part is the lower neuron system which controls vegetative life; some of its cells are in the central core which runs through the base of the brain and the interior of the spinal cord; some are situated in the ganglia which have become detached from this central core. Superimposed upon this more primitive portion of the nerve system are the lower neurons of the cerebrospinal system, with their cell bodies in the spinal and cranial nerve ganglia, on the afferent side, and in the ventral gray matter of cord and lower brain, on the efferent side. Still higher, and later in development, is that group of associative or intercalated neurons interposed between the lower afferent and lower efferent neurons and constituting the white fibre tracts of the

cord and brain. These upper neurons have developed, in accordance with the needs of their exceedingly complicated associative activities, an ultimate layer of cells, surfacing the cerebrum, and connected with each other by associative and commissural fibres, and with the lower centers by projection fibres. This layer is the cerebral cortex.

Planes of Nerve Activity.

Nerve activity may be said to occur in several planes. This is not because there is any essential difference in the nature of the nerve impulses generated by different nerve cells, but rather because of differences in organization, arrangement, and communication of the nerve elements in different parts of the nerve system.

The planes of nerve action may be termed **reflex, conscious,** and **intermediate.**

Reflex Action is that which takes place without consciousness or volition, through the action of the lower centers. An impression is received at periphery, transmitted to a nerve center, and a response there occurs without the necessary intervention of the will. A reflex action is **always** in response to a peripheral stimulus. This type of action is that which usually controls the vegetative activities of the body. It is the type which dominates the sympathetic division of the nerve system. It is the simplest form of nerve action and in lower animals the only form.

Conscious Action is that in which the mind of the subject becomes aware of sensation, reasons upon it, and decides upon and commands a response (*volitional action*), or correlates the impression with others previously received and stores it for later use (*memory*), or makes it the basis for a series of purely psychic recombinations without physical response (*thinking*). Conscious nerve action is the function of the cortex of the brain and is not possessed by any other nerve tissue; it is the highest and newest form of nerve activity, not found in the lower forms of animal life.

At this point it should be remarked that the brain has power to take over and perform consciously a great many functions which are ordinarily performed reflexly. This is especially true of muscular actions, many of which are habitually performed without the intervention of the mind except to initiate or stop them, but which can at will be taken over and definitely regulated.

This brings us to the **Intermediate** form of nerve action, which of all is most elusive and hard to study. A multiplicity of functions, obviously involving co-ordination of the highest quality between divers nerve elements, occur ordinarily without the intervention of the will and without consciousness, yet are manifestly beyond the scope of mere reflex action. Included in this category are the so-called "co-ordinated reflexes" which have to be educated into being, such as walking, running, standing. Here are acts which are at first performed only by reason of volition but which, through frequent repetition, are taken over by subordinate nerve centers which are able thereafter to execute them perfectly without requiring the attention of the conscious mind.

Similarly, many of the complex co-ordinations which occur within the body and are related to its growth, nutrition, and repair, are difficult to ascribe to reflex action alone; they appear to involve the direct application of intelligence, yet we are unconscious of their performance.

The term "sub-conscious mind" was applied by Hudson to a department of the mind of which we are unaware, in which memories are stored, and which governs our bodies while we sleep. We do not intend here to go into the possible residence, scope, and limitations of the subconscious. Its primary organ of expression is evidently the brain; it cannot be ascribed to a particular localization in the brain, but apparently mingles with the conscious mind in the use of any part of the cortex. It appears, in fact, that instead of our having two minds there is but one, of which the Conscious and Subconscious are departments, the threshold between them advancing or receding from time to time.

The Emotions in Health and Disease.

The chief seat of the emotions appears to be in the basal ganglia, optic thalamus, corpus striatum, and related nuclei. The intimate connections of these ganglia with the cortex brings about registration of all emotional changes in the cortex and evokes response there in sensation, ideation, and motion, but the real seat of the emotions is probably in the basal ganglia. They are to some degree uncontrollable, although often susceptible of inhibition or control by the will, or of neutralization by reasoning.

There is no doubt that profound emotion often produces a positive physical effect upon the entire organism. This is apparently

brought about by the fact that in close relation to the emotional nerve centers are centers for the control of the secretion of the endocrinous and some of the other glands of the body, and also vasomotor and metabolic centers. The optic thalamus is particularly important as an emotional center, containing as it does a general pain center, a general temperature center, and a general secretory center with important subdivisions.

Obstruction to Nerve Flow.

Since every function of every organ and tissue of the body depends upon the reception of proper nerve stimuli, and since for each function and part there is a specific nerve pathway by which the central nerve system sends out these stimuli, it follows that any blocking of a nerve pathway will result in diminution or alteration of function in some part, and that the location of this effect can be definitely determined if the exact location of the "block" or obstruction be known.

This principle applies equally to the inhibiting functions of neurons. The upper neurons which descend from the cerebral cortex to the ventral horn cells of the cord exercise over the lower neurons an inhibitory control which normally regulates their reflex response to peripheral stimuli. An obstruction anywhere in the course of the cerebrospinal tract, which blocks this pathway, will result in the loss of that inhibitory influence and the consequent over-strong response of the ventral horn cells. The spasticity and exaggerated reflexes which occur in hemiplegia are examples of this effect.

Similarly, obstruction of the flow of nerve energy through the rami communicantes by way of which the cerebrospinal system controls the sympathetic ganglia may result in a too-free activity of the ganglia, or in a lack of harmony of action between ganglia. The ganglia are capable of a limited amount of independent action, but their co-ordination depends upon continuity of connection with the central system.

Obstruction of the flow of nerve energy through a peripheral motor nerve results in a diminution of the function of the organ supplied by the nerve. If the interruption of transit is complete there is complete loss of function—paralysis—with atrophy both of the nerve fibre and of the muscle.

Obstruction of the flow of energy through a peripheral afferent nerve results in a loss of sensation of the kind usually carried by

that nerve and applying to the area of its distribution, and also of the loss of the influence of that sensory neuron upon motor cell groups to produce reflex action.

To sum up, any destruction of nerve tissue, any impingement upon a neuron which interrupts or modifies its structural integrity and therefore impedes its carrying power, will result in the loss or modification of the function of the organ or tissue supplied by that nerve pathway.

AIDS TO STUDY

AIDS TO STUDY

The student who desires to make inventory of his knowledge of neurology after completing the foregoing text will find the following list of questions of practical assistance. They are numbered for convenience in reference, serially arranged in the order in which their subjects appear in the preceding pages, and carefully worded so as to be susceptible of exact answers.

Teachers may find the questionnaire serviceable for reviews or examinations. It is hoped that it may prove of use to practitioners preparing for state examinations.

A difficulty which frequently attends the use of questions is a lack of general understanding as to the precise meaning of the terms in which the inquiries are couched. It is advisable, therefore, to explain the author's understanding of the most used terms.

Define.

A common question is: Define the term . . . . . "A definition of anything is a description of that thing which includes everything in the class named and excludes everything else." This definition of a definition is borrowed from some unremembered source, but is eternally true. It provides a scale by which the student may determine whether the statement he desires to use is truly a definition.

An example of the use of this formula may be cited as follows:

Q. Define the term ganglion.

A. A ganglion is an aggregation of nerve-cells, supported by a connective tissue stroma, and containing also nerve-fibres, blood-vessels, and neuroglia.

Examination of the entire nerve system discloses that there is no ganglion which does not come within the limits of this definition, and the very first statement of the definition excludes everything outside the nerve system. Furthermore, every ganglion is described; there are no essential facts about any ganglion which are not stated. This definition applies to the brain as a whole—and the brain is considered by the best authorities as a great ganglion. It describes masses within the brain, such as the optic thalamus—and anatomists classify the thalamus as a ganglion.

A question beginning "What is————?" usually requires a definition.

Repeated application of this system of measurement will train the mind in systematic arrangement and classification of knowledge. It makes for scientific thinking.

Describe.

A question calling for a description of an object may be variously worded; it may say "describe completely", or "briefly describe." In the former case it is really equivalent to saying, "Tell all you know about the structure named." In the latter, it is sufficient to set down in concise form the most essential and distinctive features of the named part; a brief description may be little more than a definition. It should always be understood that any description will go more into detail than a mere definition, and that a complete description is intended fully to reveal the student's knowledge.

A description, brief or full, should be orderly. It should proceed according to a definite plan. The plan may be varied to suit the subject and the student's preferences, but no description is a good one which is not plainly based on a systematized arrangement of facts.

In describing an anatomical structure the ensuing order may be suggested

(a) The class to which the part or structure belongs.

(b) Location. (1) In what region? (2) In what relation to adjacent structures?

(c) Shape.

(d) Size (*or dimensions*).

(e) External appearance. Irregularities or pecularities of surface.

(f) Internal structure.

It may or may not be necessary to divide the latter two items into several subdivisions, according to the part which is being described. Some parts require additional points of description; there is no fixed formula, but if the student will ask himself, "What is there to tell about this structure?" and then make a terse outline

and follow it, he will usually achieve the object of the question, which is to find out just what he knows.

Describe a Process.

The outline for description of a process naturally deals with action rather than with structure. The answers to the following questions will usually develop into a good description of a process:

(a) Where does the process occur?

(b) By what is it performed?

(c) How is it induced or excited?

(d) How or when is it checked or ended?

(e) Trace in sequence the activities which occur.

(f) What is the duration of the process?

(g) What is its purpose?

Name.

When a question merely asks that a certain thing or things be named, the answer should be brief and direct. This question is not intended to include any description whatever. It need not even be answered in statement form, as is proper with practically every other variety of question. The answer can be read and evaluated at a glance.

Discuss.

A question calling for discussion of a subject offers the widest possible latitude. It may include a complete description and statement of the function of the part, if it be part of a functioning body, or its uses if an inanimate object. It gives opportunity for comparison of the views and opinions of different investigators, or for presenting conflicting theories if there be any. It may be extended to cover the development of a part and its analogies to other parts Indeed, there is almost no limit to the scope of a discussion unless expressly limited by the terms of the question.

Describe a Disease.

It is customary to subdivide this question and to ask specifically for statement of a limited group of facts about a disease. If, however, the question is put as above, a particular disease being

named, the answer involves a mass of detail. The following is an outline which will suffice in most cases:

(a) Etiology.

(b) Pathology.

(c) Symptoms, including course, and duration.

(d) Direct diagnosis.

(e) Differential diagnosis.

(f) Prognosis.

Whether or not suggestions for treatment should be included will depend upon the nature of the examination.

Obviously, it is more practical to separate this sort of question into its component parts and require only one of them at a time. If this is done, great care must be taken not to confuse the subdivisions; not to state pathology under the head of symptoms, or evidences of disease under etiology.

Other Forms.

There are innumerable other forms which questions may take, many of which will be used in the succeeding list. The above examples should be enough to prepare the reader for close examination of the phrasing of each question; to teach him to discriminate between words having even slightly different meanings; and to train his mind to orderly preparation of his knowledge for statement. Nothing is more indicatory of incomplete preparation and confusion of mind than an answer in which important facts and trivial are inextricably mixed and in which facts of the same class or group are scattered throughout a discussion.

QUESTIONS ON ANATOMY AND HISTOLOGY

Refer to index for page numbers.

1. Define neurology.
2. What are the major subdivisions of neurology?
3. Into what two groups are the nerve organs divided? Name the chief subdivisions of each group.
4. Define the term "neuron".
5. Discuss the neuron theory.

6. Describe a typical neurocyte.
7. What are dendrites? How may a dendrite be distinguished from an axon?
8. Describe a typical axon.
9. What is meant by "unipolar cell"? Monaxonic cell? Diaxonic? Polyaxonic?
10. Define neuroglia.
11. Describe the structure of a nerve (*nerve trunk*).
12. Describe the neurilemma.
13. Describe the myelin sheath.
14. What are nodes of Ranvier?
15. What are the nervi nervorum? What is their function?
16. What is meant by "real origin" of nerves? Apparent origin? Superficial origin? Deep origin?
17. What are nuclei of termination?
18. Define the term "ganglion".
19. What are pre-ganglionic fibres? Post-ganglionic?
20. How are plexuses formed?
21. How do nerves terminate in skeletal muscle tissue. In visceral muscle? In glands?
22. State the dimensions of the spinal cord (*medulla spinalis*).
23. Briefly describe the cervical enlargement of the spinal cord; the lumbar enlargement.
24. By what membranes is the spinal cord surrounded?
25. What and where is the dentate ligament?
26. Locate and describe the fissures of the spinal cord.
27. Tell how the nerve-roots are attached to the cord.
28. Briefly describe the internal structure of the medulla spinalis.
29. Of what is the gray matter of the cord made up?
30. Describe the columnar arrangement of nerve cells in the anterior. horns.
31. Describe the dorsal nucleus (*Clark's vesicular column*).
32. What three systems of fibres are represented in the white matter of the cord?
33. Define the term "fasciculus" as applied to the spinal cord.
34. Locate the fasciculi proprii.
35. Name the tracts in the ventral funiculus of the cord.
36. Describe the anterior cerebrospinal fasciculus.

37. Describe the vestibulospinal fasciculus.
38. Describe the tectospinal tract.
39. Name, and classify as to direction, the tracts in the lateral funiculus of the cord.
40. Describe the lateral cerebrospinal tract.
41. Describe the rubrospinal tract.
42. Describe the direct spinocerebellar tract.
43. Describe the ventral spinocerebellar tract.
44. What is included in the "tract of Gowers"?
45. Describe the lateral spinothalamic fasciculus.
46. Describe the spinotectal tract.
47. Name the tracts of the posterior funiculus of the spinal cord.
48. Describe the tract of Lissauer.
49. Describe the fasciculus gracilis.
50. Describe the fasciculus cuneatus.
51. What is the relation of the dorsal root fibres at different levels of the cord to the fasciculus gracilis and fasciculus cuneatus?
52. Describe the ventral root of a spinal nerve. The dorsal root.
53. Trace the disposition of the entering dorsal root fibres within the cord.
54. What is the encephalon?
55. Name the three embryonic divisions of the brain.
56. Name the parts of the hind-brain.
57. Locate the medulla oblongata.
58. Describe the external appearance of the medulla.
59. Compare the internal structure of the medulla oblongata with that of the spinal cord.
60. What and where is the pyramidal decussation?
61. What and where is the decussation of the lemnisci?
62. Describe the restiform body.
63. How and where do the fasciculi gracilis and cuneatus end?
64. What is the medial longitudinal bundle?
65. Briefly describe the arcuate fibres of the medulla.
66. Name and locate as many nuclei of the medulla as possible.
67. Describe the external appearance of the pons Varolii.
68. Describe the internal structure of the pons.
69. What fibre tracts are found in the dorsum (*tegmentum*) pontis?

70. What tracts traverse the pars basilaris pontis?
71. What are the nuclei pontis?
72. Which cranial nerves have nuclei in the pons? In the medulla?
73. Locate the nucleus of the hypoglossal nerve.
74. Locate the nucleus of the spinal accessory nerve.
75. Locate the nucleus of the vagus nerve.
76. Locate the nucleus of the glossopharyngeal nerve.
77. Locate the nuclei of the eighth nerve.
78. Locate the nuclei of the facial nerve.
79. Locate the nucleus of the abducent nerve.
80. Locate the trigeminal nerve nuclei.
81. Briefly describe the cerebellum.
82. Name the lobes of the cerebellum.
83. Name the nuclei in the interior of the cerebellum.
84. What is meant by "arbor vitae"?
85. How is the cerebellum connected with the brain-stem?
86. Describe the superior peduncles; middle; inferior.
87. What is the valve of Vieussens?
88. State briefly the structure of the cerebellar cortex.
89. What and where is the fourth ventricle?
90. Of what structures is the roof of the fourth ventricle made up?
91. Briefly describe the floor of the fourth ventricle.
92. What structures comprise the mid-brain.
93. Briefly describe the corpora quadrigemina.
94. Describe the external appearance and relations of the cerebral peduncles.
95. What fibre tracts traverse the crusta of the cerebral peduncles? The tegentum?
96. What is the substantia nigra?
97. Describe the red nucleus.
98. Describe the fronto-pontine tract. The temporo-pontine.
99. Give the origin, destination, and function of the medial lemniscus.
100. Give origin, destination, and function of the lateral lemniscus.
101. Describe the cerebral aqueduct.

102. What are the two major divisions of the fore-brain?
103. Name the developmental parts of the diencephalon; of the telencephalon.
104. Of what is the thalamencephalon composed?
105. Describe the location and external appearance of the optic thalamus.
106. Describe briefly the internal structure of the optic thalamus.
107. What are the connections of the optic thalamus?
108. Briefly describe the medial geniculate body; the lateral.
109. Describe the pineal body.
110. Briefly give the boundaries of the third ventricle.
111. What and where are the mammillary bodies?
112. Describe the hypophysis cerebri. By what other name is it known?
113. Describe the external appearance and location of the optic chiasma.
114. Describe the arrangement of fibres within the optic chiasma.
115. Describe the external appearance of the optic tracts.
116. Of what fibres is each optic tract composed?
117. Trace the optic tract fibres into the substance of the brain.
118. Name the lower visual centers.
119. Define "optic radiations"; "auditory radiations".
120. Name the openings into the third ventricle.
121. Name and locate the openings into the fourth ventricle.
122. Name the parts of the telencephalon.
123. Of what three parts is each cerebral hemisphere made up?
124. Describe the corpus callosum.
125. Briefly describe the surface of the cerebral hemispheres.
126. Name the principal fissures of the cerebrum.
127. Describe the fissure of Sylvius.
128. Describe the fissure of Rolando.
129. Describe the calcarine fissure.
130. Describe the cingulate sulcus.
131. Describe the circuminsular fissure.
132. Describe the collateral fissure.
133. Name the lobes of the cerebrum. Give boundaries of each.
134. Into what gyri is the frontal lobe divided?

135. What are the divisions of the parietal lobe?
136. How is the occipital lobe subdivided?
137. What are the subdivisions of the temporal lobe?
138. Describe the Island of Reil.
139. Briefly describe the rhinencephalon.
140. What name is given to those connections of the olfactory nerves which develop with the neopallium? Name the parts.
141. Briefly describe the olfactory bulb; the olfactory tract.
142. Define the term "lateral ventricle".
143. What is the shape of the lateral ventricles? What openings have they?
144. What and where is the hippocampus?
145. What are the parts of the corpus striatum? Why is it so named?
146. Trace the fibre connections of the corpus striatum.
147. What is the claustrum?
148. What and where is the amygdala?
149. Locate the internal capsule.
150. Describe the arrangement of the fibre tracts in the internal capsule.
151. Why is the internal capsule pathologically important?
152. What and where is the external capsule?
153. Briefly describe the fornix.
154. Describe the choroid plexuses of the ventricles.
155. What is the relation of the gray and the white matter in the cerebral hemispheres?
156. What is the cortex?
157. Of what fibre groups is the white matter of the cerebrum composed?
158. Name the principal afferent fibre tracts in the cerebrum.
159. Briefly describe the cerebral commissures.
160. Name the most clearly defined groups of association fibres in the cerebrum.
161. Briefly describe the structure of the cerebral cortex.
162. What is the average weight of the brain?
163. What is meant by the term "corona radiata"?
164. Name the four processes or projections from the dura mater of the brain. Briefly locate and describe each.

165. What is the structure of the cranial dura mater?
166. What is the falx cerebri? Falx cerebelli? Tentorium cerebelli? Diaphragma sellae?
167. Describe the arachnoid membrane.
168. Describe the pia mater.
169. What is the cisterna pontis?
170. What are the subdivisions of the peripheral nerve system?
171. Name the cranial nerves in order.
172. Which cranial nerves are motor? Which sensory? Which mixed?
173. Locate the "pituitary area".
174. What and where is the Schneiderian membrane?
175. Where are the cells of origin of the olfactory nerve fibres?
176. Describe the dendrites of the olfactory nerve cells.
177. Give the nuclear connections of the olfactory nerve.
178. Describe the olfactory nerve.
179. By what pathway is the blood-supply and nutrition of the olfactory nerve controlled?
180. Define: Retina; macula lutea; fovea centralis.
181. Explain the blind spot in the retina.
182. Name the seven layers of which the retina is composed.
183. Describe the rods and cones of the retina. How many are there of each, approximately?
184. Describe the optic nerve.
185. Describe the optic decussation.
186. How many fibres are estimated as composing the optic nerve?
187. Describe the real origin of the oculomotor nerve.
188. What is the anatomic relation between the oculomotor and abducent nerves?
189. Name the muscles innervated by the oculomotor nerve.
190. With what ganglion is the third nerve connected? How?
191. Describe the superficial origin and course of the third nerve.
192. What nerves leave the skull through the superior orbital fissure and in what relation to each other?
193. Describe the sympathetic connections with the oculomotor nerve.
194. Outline the important facts about the trochlear nerve.

195. Which nerve supplies most afferent fibres to the cranial dura mater?
196. Locate the sensory nuclei of the trigeminal nerve. The motor nuclei.
197. Describe the mesencephalic root of the trigeminal.
198. What is the superficial origin of the trigeminal nerve?
199. Name the three major divisions of the trigeminal.
200. Where are the cells of real origin of the afferent elements of the trigeminal?
201. Which branches of the trigeminal are motor; sensory; mixed?
202. Trace the course of the ophthalmic nerve. Name its principal branches.
203. What nerve twice leaves the skull?
204. What is the relation of the ciliary ganglion to the fifth nerve?
205. Locate and describe the ciliary ganglion, with its connections.
206. Locate and describe the spheno-palatine ganglion, with its connections.
207. Locate and describe the otic ganglion. The submaxillary ganglion.
208. Give distribution of the branches of the ciliary ganglion; the spheno-palatine; the otic.
209. Describe the course taken by the maxillary nerve. Name its important branches.
210. Describe the course of the mandibular nerve. Name its branches.
211. What is the relation of the chorda tympani to the fifth nerve?
212. Describe the deep petrosal nerve.
213. Describe the greater superficial petrosal nerve.
214. Describe the nerve of the pterygoid canal. State its other name.
215. Name all the nerves to the eye.
216. Name the nerves to the teeth.
217. What nerves are distributed to the nose?
218. What nerves supply the tongue?
219. Make an outline of the principal facts about the trigeminal nerve.
220. Explain the origin of the abducent nerve.
221. What is the relation of the abducent to the third nerve?

222. State the apparent origin and course of the abducent nerve.
223. Give the distribution of the abducent nerve.
224. With what other nerves does the abducent communicate?
225. To what class of nerves does the facial belong?
226. Describe the roots of the facial nerve.
227. What are the nuclear connections of the facial nerve?
228. What and where is the nervus intermedius?
229. What is the relation of the nervus intermedius to the facial nerve? To the chorda tympani?
230. Describe the course of the facial nerve.
231. What is the genu facialis internum? Genu facialis externum?
232. With what other nerves does the facial communicate?
233. Describe the entire course of the fibres of the chorda tympani.
234. Make an outline of the facial nerve.
235. Of what divisions is the acoustic nerve composed?
236. Describe the course and distribution of the eighth nerve.
237. Describe the nuclear connections of the eighth nerve.
238. By what nucleo-cortical pathway do auditory impressions travel?
239. By what pathway may impressions from the semicircular canals influence the action of skeletal muscles?
240. Make an outline of the eighth cranial nerve.
241. What is the distribution and function of the glossopharyngeal nerve?
242. What is the relation between the glossopharyngeal and the chorda tympani?
243. What ganglia are found on the ninth nerve? What is their relation to it?
244. Describe the course of the ninth nerve.
245. Make an outline of the glossopharyngeal nerve.
246. Describe the origin and course of each vagus nerve.
247. Name and describe the ganglia of the vagus.
248. With what plexuses does the vagus communicate?
249. Of what five groups of fibres is the vagus nerve composed?
250. What is the nerve of Arnold?
251. Describe the laryngeal branches of the vagus.
252. Describe the vagal cardiac nerves.
253. Describe the terminations of the vagus in the abdomen.

254. Make an outline of the vagus nerve.
255. Describe the spinal accessory nerve.
256. Make an outline of the hypoglossal nerve.
257. How many spinal nerves are there and in what groups are they described?
258. What is the real origin of the motor elements of the spinal nerves? The sensory elements?
259. What types of cells are found in the spinal ganglia?
260. Locate the spinal ganglia.
261. State how the spinal nerve roots are related to the surface of the cord.
262. Discuss the size and direction of spinal nerve roots.
263. What types of fibres are contained in a typical spinal nerve?
264. Trace the course of each of the above types of fibres.
265. Where does the first subdivision of the spinal nerve occur? Into what does it divide?
266. Describe the posterior primary division of the first cervical nerve.
267. Describe the posterior division of the second cervical nerve.
268. What is the distribution of the posterior divisions of the lower five cervical nerves?
269. What structures are innervated by the posterior divisions of the thoracic nerves? The lumbar nerves? The sacral?
270. Describe the manner of formation of the cervical plexus.
271. Name the branches given off by the cervical plexus.
272. Describe the smaller occipital nerve.
273. Describe the great auricular nerve.
274. With what nerves does the cervical plexus communicate?
275. What is the origin of the phrenic nerve?
276. Describe the course of the two phrenic nerves.
277. State distribution and function of the phrenic nerve.
278. Define "brachial plexus".
279. What nerves enter into the formation of the brachial plexus?
280. Locate the brachial plexus.
281. Describe the formation of the brachial plexus.
282. With what nerves does the brachial plexus communicate?
283. Name the branches of the brachial plexus.
284. Describe the long thoracic nerve.

285. Give origin, course, and distribution of the musculocutaneous nerve.
286. Describe the axillary nerve.
287. Describe the medial antibrachial cutaneous nerve.
288. Describe the medial brachial cutaneous nerve.
289. What is the origin, course, and distribution of the median nerve?
290. What branches are given off by the median nerve?
291. Give origin, course, and distribution of the ulnar nerve.
292. What branches are given off by the ulnar nerve?
293. Give origin, course, and distribution of the radial nerve.
294. What branches are given off by the radial nerve?
295. By what other name is the musculospiral nerve known?
296. What name is given to the anterior primary divisions of the thoracic nerves?
297. Give distribution of the intercostal nerves.
298. Describe the anterior division of the first thoracic nerve.
299. Describe in general the anterior divisions of the thoracic nerves from second to fifth inclusive.
300. Describe the thoracico-abdominal intercostal nerves.
301. Describe the anterior division of the twelfth thoracic nerve.
302. Of what parts is the lumbosacral plexus made up?
303. What is the lumbosacral trunk?
304. What is the "nervus furcalis"?
305. Locate the lumbar plexus and state how it is formed.
306. Name in order the branches of the lumbar plexus.
307. Describe the ilioinguinal nerve.
308. Describe the iliohypogastric nerve.
309. Describe the genito-femoral nerve.
310. Describe the lateral femoral cutaneous nerve.
311. Describe the obturator nerve.
312. Describe the accessory obturator nerve. In what percentage of cases is it present?
313. Give origin, course, and termination of the femoral nerve.
314. What are the branches of the femoral nerve?
315. How is the sacral plexus formed?
316. What is the largest branch of the sacral plexus?
317. Name the branches of the sacral plexus.

318. Describe the posterior femoral cutaneous nerve.
319. How is the sciatic nerve formed? Give its course and termination.
320. Of what two divisions is the sciatic nerve composed? Which is the larger?
321. What branches are given off by the sciatic nerve before dividing?
322. Describe the origin, course, and termination of the tibial nerve.
323. What branches does the tibial nerve give off?
324. Give the origin, course, and termination of the deep peroneal nerve.
325. What are the divisions of the common peroneal nerve?
326. Describe the deep peroneal nerve.
327. Describe the superficial peroneal nerve.
328. How is the pudendal plexus formed? Locate it.
329. Describe the pudendal nerve and name its branches.
330. Name all the nerves which supply the hip-joint.
331. Name all the nerves which supply the knee-joint.
332. Name the nerves which ramify the foot.
333. What is the nerve supply to the shoulder-joint? The elbow? The wrist?
334. Name the nerves which supply the tongue. The tonsil. The pharynx.
335. Define the term "sympathetic nerve system". By what other names is it called?
336. Discuss and compare the various names for the sympathetic system.
337. Describe, briefly, the general arrangement of the sympathetic system.
338. Briefly describe the sympathetic trunks.
339. What is meant by "great gangliated cord"?
340. What and where is the ganglion impar?
341. Explain the connections between spinal and sympathetic nerves.
342. Name and locate the prevertebral plexuses.
343. What are "collateral ganglia"? Where found?

344. How many sympathetic ganglia are in the cervical region? Name them.
345. Locate and describe the superior cervical ganglion.
346. Name the branches of the superior cervical ganglion.
347. Describe the middle cervical ganglion and name its branches.
348. Describe the inferior cervical ganglion and name its branches.
349. How are the cervical ganglia connected?
350. Describe the cervical cardiac nerves.
351. Describe the internal carotid nerve.
352. To what collateral ganglia is the superior cervical ganglion connected?
353. What intracranial plexuses communicate with the superior cervical ganglion?
354. Locate and describe the internal carotid plexus. With what nerves does it communicate?
355. Locate and describe the cavernous plexus. With what nerves does it communicate?
356. What is the superior termination of the sympathetic system?
357. Name all the nerves to the thyroid gland.
358. How many ganglia make up the thoracic portion of the sympathetic trunk?
359. In general, how are their branches distributed?
360. With what ganglia is the great splanchnic nerve related? The lesser splanchnic? The least?
361. Describe the course and termination of the three splanchnic nerves.
362. What viscera are innervated by each splanchnic nerve?
363. What is the distribution of the branches of the lumbar ganglia of the sympathetic trunk? Of the branches of the pelvic portion?
364. Describe the formation of the cardiac plexus.
365. Tell what branches are given off by the cardiac plexus.
366. Describe the formation of the pulmonary plexuses. The esophageal.
367. Of what is the coeliac plexus made up?
368. Give relations of coeliac plexus to surrounding structures.
369. Name the branch plexuses of the coeliac.
370. What ganglia are found in the coeliac plexus? Describe them.

371. Describe the phrenic plexus.
372. Of what is the hepatic plexus made up?
373. From what source does the splenic plexus derive its fibres? By what other name is it known?
374. Describe the superior gastric plexus.
375. Of what is the suprarenal plexus made up?
376. How is the renal plexus formed?
377. Describe the formation and distribution of the spermatic plexus.
378. Locate and describe the superior mesentric plexus.
379. Locate and describe the abdominal aortic plexus.
380. Briefly describe the hypogastric plexus.
381. State the general distribution of the branches of the pelvic plexus.
382. Describe the oculomotor sympathetics.
383. What sympathetic fibres traverse the facial nerve?
384. Describe the glossopharyngeal sympathetics.
385. Describe the vagal sympathetics.
386. Name the foramina of exit from the skull of all the cranial nerves.
387. What is Jacobson's nerve?
388. What nerve is known as an aberrant branch of the glossopharyngeal?
389. Which cranial nerve has the most extensive distribution? The least extensive?
390. Which is the largest nerve in the body? The longest?

EMBRYOLOGY

391. Define "embryology".
392. Into what three sub-periods is the period of pre-natal development separated?
393. What are the chemical constituents of an animal cell?
394. Describe the structure of a typical animal cell.
395. Describe the nucleus.
396. Define nucleolus; centrosome; centriole; mittochondria; chromosome.
397. What is believed to be the purpose of mitochondria?
398. How are new animal cells formed?

399. Name the two forms of cell multiplication.
400. Under what circumstances does mitosis occur?
401. Define karyokinesis.
402. Name the two types of mitosis. Which is the commoner?
403. What are the four phases of homotype mitosis? Briefly describe each stage in turn.
404. What is the supposed relationship of the chromosomes to the sex of the individual?
405. What is the difference between heteroytpe and homotype mitosis?
406. Define "gametes".
407. Name the female gametes; the male.
408. What are "primitive germ cells"?
409. Describe the ovum.
410. Describe the development of a vesicular ovarian follicle.
411. Discuss the process of maturation of the ovum.
412. What are spermatocytes? Spermatids?
413. Name the parts of a spermatozoon.
414. What is fertilization? Where does it take place?
415. Define "zygote".
416. Describe what occurs in a zygote up to the formation of the morula.
417. Into what layers is the morula differentiated?
418. What is meant by "the embryonic area"?
419. What is the primitive streak? The notochord?
420. Describe the formation of the neural groove; the neural folds.
421. Describe the process by which the neural tube is formed.
422. What is the neurenteric canal?
423. What is meant by basal lamina? Alar lamina?
424. How are ganglia first formed in the embryo?
425. Describe the nerve cell migration of the embryo.
426. Tell how the beginnings of the sympathetic system are formed.
427. What are the brain vesicles and how formed?
428. What is the optic vesicle and what is formed from it?
429. What is the olfactory diverticulum?
430. Describe the embryological development of the medulla oblongata; of the pons Varolii; of the cerebellum.

431. From which vesicle are the cerebral peduncles formed? The corpora quadrigemina?
432. From what part of the embryonic brain is the hypophysis formed? The pineal body?
433. From what part of the embryonic brain are the geniculate bodies formed?
434. Discuss the embryonic development of the spinal cord.
435. What becomes of the elongated cavity of the neural tube?
436. Explain the formation of the ventricles.
437. How is the internal ear formed from the embryo?
438. What are neuroblasts?
439. From which embryonic layer is the spinal cord formed?
440. Out of which embryonic layer do the membranes of cord and brain develop?
441. What is the degree of development of the embryonic nervous system at the end of the third week? At the beginning of the fifth week?
442. What changes take place during the fifth week?
443. Discuss the time of medullation of the various groups of nerve fibres.

PHYSIOLOGY

444. Of what tissues is the body composed?
445. Which is the most important tissue and why?
446. What parts make up the cerebrospinal system? The sympathetic?
447. What is the true distinction between axons and dendrites?
448. How are nerve-cells described as to shape?
449. How large are nerve-cells?
450. What are neurofibrils?
451. What is the function of an axon? Of a dendrite?
452. What is the function of a neurocyte?
453. State the probable function of the neurofibrils.
454. What is the function of the neurilemma?
455. State the function of the myelin sheath.
456. What function is exercised by the collaterals?
457. What is the purpose of the nodes of Ranvier?
458. What is the general function of ganglia?

459. What are pre-ganglionic fibres? Post-ganglionic?
460. What is the collective function of the nerve trunks?
461. Explain the utility of a plexus.
462. How are nerve trunks nourished?
463. Explain the utility of the endoneurium, perineurium, and epineurium.
464. Define "efferent nerve"; "afferent nerve".
465. In what three groups are nerves classified according to their function? Give examples in each group.
466. Describe the mode of termination of efferent nerves in skeletal muscle. In visceral muscle. In gland tissue.
467. What is a neuromuscular spindle?
468. Name the principal varieties of afferent nerve endings.
469. By what is the nutritional ability of a nerve fibre governed?
470. What changes take place in an axon or dendrite severed from its cell of origin?
471. Describe Wallerian degeneration.
472. What factor determines the direction in which a cut nerve degenerates?
473. Does degeneration ever travel or spread from one neuron to another? Why—or why not?
474. Give examples of diseases in which Wallerian degeneration occurs.
475. Under what circumstances may a degenerated nerve undergo regeneration?
476. Explain the process of nerve regeneration.
477. What are the essential differences between nerve impulses in one nerve and those in another?
478. What are the functional subdivisions of efferent nerves?
479. Into what two groups, according to distribution, may afferent nerves be divided?
480. Name the two subdivisions of the tegumentary nerves.
481. How are sensorifacient nerves further subdivided? Reflex nerves?
482. How do inhibitor nerves act?
483. What is the special property of nerve tissue? Define it.
484. How is the conductivity of nerve tissue demonstrated?

485. What conditions are necessary to the maintenance of conductivity?
486. What happens to impulses transmitted through a blocked or impinged nerve?
487. Define the term "nerve stimulus".
488. By what means may a nerve be excited to activity?
489. What form of stimulus most frequently excites nerves?
490. What is the difference between the nerve impulse in a motor nerve and that in a vaso-motor nerve? Between vaso-motor and secretory?
491. What is the effect of overexcitation of a nerve and where is this effect expressed?
492. What is the effect of obstruction of a nerve channel and where expressed?
493. In what two groups are classed the factors which may stimulate a nerve?
494. Name the varieties of general stimuli which may influence nerves.
495. Name the special stimuli which influence nerves.
496. Discuss the nature of the nerve impulses. Give reasons for the view stated.
497. What is the average rate of conduction of afferent nerve impulses? Of efferent impulses?
498. What is meant by "reaction of degeneration"?
499. Under what conditions is the reaction of degeneration developed?
500. What effect has degeneration upon the function of a nerve?
501. What are "intercalated neurons"?
502. Discuss the physiologic importance of the intercalated neurons.
503. Where, in the human body, are intercalated neurons found?
504. Define "reflex action".
505. What is a "nerve center"?
506. What is the difference between reflex and voluntary action?
507. State what structures are essential to a reflex mechanism.
508. Describe a simple reflex arc.
509. Trace the passage of energy through a simple reflex arc.
510. Describe briefly the mechanism of a complex reflex.

511. By what mechanism is reflex action checked or governed in the body?
512. Cite examples of reflexes which may be regulated by the will under ordinary circumstances.
513. Name some reflexes which cannot be regulated by the will.
514. Name some reflexes which may be influenced by emotions.
515. In what part of the nerve system are most of the reflex centers located?
516. Define "paralysis". Distinguish between inhibition, paralysis, and fatigue of nerves.
517. What is the two-fold influence of the cerebrospinal neurons upon the ventral gray matter of the cord?
518. What is a "nerve organ"?
519. What function is common to all nerve organs?
520. What are the functions of the nerve system as a whole?
521. What is the function of a neuron?
522. What is the relation of nerve energy to muscular activity.
523. What structures are found in the gray matter of the spinal cord?
524. Name the three classes of nerve cells in the spinal gray matter.
525. Define: afferent cell; efferent cell; intrinsic cell.
526. Where are the afferent cells of the cord chiefly located? The efferent cells?
527. By what methods of investigation has the white matter of the cord been subdivided into tracts?
528. What is the function of the fasciculus gracilis? Fasciculus cuneatus?
529. Explain the physiologic relation between the fasciculus gracilis and the medial lemniscus.
530. Do any impulses ascending by the gracile and cuneate fasciculi reach the cerebellum? If so, by what pathway? What use is made of them?
531. State the function of the tract of Lissauer.
532. What is the function of the fibres in the comma tract of Schultz?
533. What is the function of the fasciculi proprii?
534. What is the function of the fibres of the dorsolateral spinocerebellar tract?

535. State the function of the cells of the dorsal nucleus.
536. Trace the course of the impressions which pass through the ventral spinocerebellar fasciculus.
537. What is the function of the spinothalamic tracts? Spinotectal?
538. State the function of the lateral cerebrospinal tract. The ventral cerebrospinal.
539. What is the function of the tectospinal tract? The vestibulospinal?
540. Discuss the function of the rubrospinal fasciculus.
541. Describe the direct motor pathway. The indirect.
542. Describe the direct sensory pathway. The indirect.
543. Locate and describe the motor and sensor decussations.
544. By what pathway do touch impressions travel? Pain? The muscular and tendinous sense? Temperature?
545. What fibres are contained in the anterior commissure of the cord?
546. What effects follow division of the anterior roots of the spinal nerves?
547. What are the effects of stimulation of the anterior roots?
548. What effects follow division of the posterior roots? Stimulation?
549. Discuss the superior and inferior planes of nerve activity.
550. Discuss the segmentation of the medulla spinalis.
551. What is meant by the term "spinal cord center"?
552. What factors bring about the discharge of energy by spinal cord centers?
553. What is meant by "autochthonic action"?
554. Explain trophic tonus.
555. Define and explain vascular tonus.
556. Explain muscle tonus.
557. Define "reflex action".
558. What faculty of nerve cells is the basis of memory and association of ideas?
559. Name some conditions which augment or exaggerate the reflexes.
560. Name some conditions which will diminish or abolish the reflexes.

561. State Pfluger's Laws of Reflex Action.
562. How do neurons communicate with each other?
563. What change in the distribution of stimuli occurs when afferent neurons are excessively stimulated?
564. Name the three classes of reflexes.
565. Name and briefly describe the superficial reflexes.
566. Name and briefly describe the deep reflexes.
567. Name several organic reflexes.
568. Discuss intersegmental conduction in the cord.
569. What effects follow section of the pyramidal tract?
570. What effects follow stimulation of the cut end of the pyramidal tract?
571. Explain in general the relation of the cranial nerves to the brain.
572. In general, what are the functions of the medulla oblongata?
573. How do they compare with those of the cord?
574. Discuss the medulla as a reflex center.
575. Name ten nerve centers in the medulla and pons.
576. What important fibre tracts pass through the medulla?
577. What are the functions of the pons Varolii?
578. What function is performed by the arcuate fibres of the medulla?
579. State the function of the restiform body.
580. What is the function of the middle peduncles? The superior?
581. State the function of the nuclei pontis.
582. What, in general, is the function of the cerebellum?
583. What is the function of Deiter's nucleus? Of the nucleus ambiguus?
584. What important nuclei are located in the mid-brain?
585. What fibre tracts pass through the crusta of the mid-brain? The tegmentum?
586. What is the function of the red nucleus?
587. State the functions of the corpora quadrigemina (*colliculi*).
588. State the known functions of the optic thalami.
589. What are the functions of the geniculate bodies?
590. What three groups of white fibres are found in the cerebrum?
591. What is the function of the internal capsule?

592. State the function of the fronto-pontine tract. The temporo-pontine.
593. What is the general function of the cerebral cortex?
594. Explain the relation of the cortex to the lower centers.
595. Define "motor impulses"; "sensory impressions".
596. Explain the degree to which the cortex regulates motor activity.
597. Briefly explain the function of memory.
598. Discuss the localization of cortical function.
599. Locate the motor area of the cerebral cortex. The sensory area.
600. Where is the visual sensory area of the cortex? The auditory sensory area?
601. Explain how a motor function may be resumed after destruction of its cortical area of representation.
602. What is "Broca's area" and where located?
603. State the general functions of the sympathetic system.
604. Name the classes of efferent sympathetic fibres according to the functions they excite.
605. Discuss the functional relation of the sympathetic to the cerebrospinal system.
606. What are the functions of the ciliary ganglion?
607. What are the functions of the spheno-palatine ganglion?
608. What are the functions of the otic ganglion? The submaxillary?
609. State the general functions of the cervical sympathetic.
610. What is the relation of the cervical sympathetic ganglia to the spinal cord?
611. State the general functions of the thoracic sympathetic ganglia.
612. What is the function of the greater splanchnic nerve? The lesser? The least?
613. What are the most marked effects of stimulation of the greater splanchnic nerve? Of division of that nerve?
614. What are the functions of the coeliac plexus?
615. What are the functions of the lumbo-sacral sympathetic?
616. What is a "special nerve mechanism"?
617. Briefly describe the nerve mechanism of voluntary movement.

618. Explain the nerve mechanism of digestion, in brief.
619. Explain the nerve mechanism of prehension.
620. Explain the function of mastication.
621. Explain the process and nerve mechanism of insalivation.
622. What nerves enter into the function of deglutition?
623. Is swallowing voluntary or reflex?
624. Explain the nerve action in gastric digestion.
625. Explain the influence of nerves in intestinal digestion.
626. Explain the nerve mechanism of defecation.
627. What is the relation of nerves to absorption?
628. Explain the nerve mechanism of blood circulation.
629. From what source is it controlled?
630. Describe the nerve mechanism to the heart and tell how it acts.
631. Discuss the myogenic and neurogenic theories of cardiac action.
632. Explain the nerve mechanism of respiration.
633. Explain the nerve mechanism of phonation.
634. How is animal heat produced?
635. How is animal heat expended?
636. By what process is a balance maintained between heat production and heat expenditure?
637. What are the most important nerve factors in maintaining normal temperature?
638. Locate the temperature-regulating centers.
639. Explain the phenomena of fever?
640. Explain the nerve mechanism of secretion.
641. What nerve pathway influences thyroid secretion? Suprarenal?
642. Describe the nerve mechanism of urination.
643. Explain the perspiratory nerve mechanism.
644. Explain the nerve mechanism of reproduction.
645. What are "nerves of special sense"?
646. What factors determine whether a nerve is a nerve of special sense or one of general sense?
647. Define the sense of touch.
648. What special nerve endings are concerned with touch?
649. Name the varieties of tactile impressions.

650. Tell how to test each variety of tactile sense.
651. Upon what does the recognition of temperature depend?
652. Trace the pathway by which temperature impressions travel.
653. What is pain? How is it evoked?
654. By what pathway do pain impressions travel?
655. Explain "referred pains".
656. What is the "muscle sense"? By what pathway is it transmitted?
657. Explain the mechanism of taste.
658. What special stimuli are required to evoke taste?
659. What is the special stimulus for the sense of smell? Explain the mechanism of smell.
660. What special stimulus is required to develop vision?
661. What is the function of the retina?
662. What is the special function of the rods and cones?
663. Explain the formation of the retinal image.
664. Explain the nerve control of the iris and its function.
665. What part do the ocular muscles play in vision. Give their nerve supply.
666. By what mechanism do visual impressions evoke contractions of skeletal muscles?
667. What is the effect of a lesion of one optic nerve? Of one optic tract?
668. Trace the visual impression from cornea to cortex.
669. What is the pathway by which the pupillary reflex is controlled?
670. What is the function of the Eustachian tube?
671. What is the function of the organ of Corti?
672. What is the function of the semicircular canals?
673. Trace the pathway by which auditory impressions travel between the tympanum and the cortex.
674. What is the function of the external ear?
675. Explain the function of the tympanum. The ossicles.
676. Briefly describe the mechanism by which equilibrium is maintained.

SYMPTOMS AND DIAGNOSIS

677. Distinguish between organic and functional nerve disorders.

678. What are the two major objectives in the diagnosis of organic nerve disorders?
679. Describe the process of reasoning from symptoms to the location of a nerve lesion.
680. Define the terms "upper neuron" and "lower neuron".
681. Locate the nuclei of origin of the lower motor neurons.
682. Restate the functions of the upper neuron system as compared with those of the lower neurons.
683. What trophic relation exists between the parts of a neuron?
684. Locate the upper and lower sensory neuron systems.
686. From what source is the nutrition of sympathetic neurons neurons governed? The upper?
686. From what source is the nutrition of sympathetic neurons governed?
687. What effect has a spinal cord lesion upon the functions of the sympathetic?
688. State in a few words the direct effect of all nerve lesions.
689. Define spasm; convulsion; tonic spasm; clonic spasm.
690. In general, what are the causes of spasm?
691. What is tremor? Explain it.
692. How does one test for tremor?
693. What is coarse tremor? Fine tremor? Passive tremor? Active tremor?
694. Under what conditions does pathological tremor occur?
695. Define athetosis.
696. What is Jacksonian epilepsy?
697. Describe the movements of chorea.
698. What is a cramp? A contracture?
699. What is tetany?
700. Define paralysis; palsy; paresis; amyosthenia.
701. Define hemiplegia; diplegia; paraplegia; monoplegia.
702. What five questions must be answered during an examination of a patient to detect paralysis?
703. What are the characteristics of upper neuron paralysis? Of lower?
704. Where are the commonest causes of upper neuron paralysis located?
705. What are the commonest pathological causes of hemiplegia?

706. What are the possible locations of lesions causing lower neuron paralysis?
707. Name the clinical features of lower neuron paralysis.
708. What is the chief distinction between lower neuron paralysis due to lesion of a peripheral nerve or nerves and that due to spinal cord lesion?
709. What is dystrophy?
710. What is meant by "cerebral type of paralysis"? "Spinal type"?
711. To what cause are functional paralyses chiefly due?
712. Give an example of a mixed type of paralysis.
713. To what cause is hemiplegia usually due? Incomplete hemiplegia?
714. Give an explanation of crossed hemiplegia.
715. How can you determine the extent of a lesion in the internal capsule?
716. To what is hemiplegia with crossed oculomotor paralysis due?
717. Explain hemiplegia with crossed facial paralysis of the atrophic type.
718. What is the significance of hemiplegia plus anarthria?
719. To what is sudden hemiplegia usually due? Name five other possible causes of hemiplegia.
720. Name the commonest causes of paraplegia inferior.
721. Locate the lesions of spastic paraplegia as distinguished from those of flaccid paraplegia.
722. Name the diseases which may cause spastic paraplegia. Flaccid.
723. To what causes may monoplegia be due?
724. Give the names applicable to monoplegias in various locations.
725. Distinguish between supra-nuclear and infra-nuclear facial nerve paralysis.
726. How would you diagnose facial paralysis?
727. How locate with accuracy the site of a lesion causing facial nerve paralysis?
728. What senses should be examined in connection with a complete examination of the nervous system?
729. Tell briefly how hearing may be tested.
730. What are the two types of deafness? How may they be distinguished?

731. Name some of the commonest causes of deafness.
732. What is tinnitus aurium? How caused?
733. Describe the examination of the sense of taste.
734. Define ageusia. Cite some of its causes.
735. State how the sense of smell may be tested.
736. Define anosmia. Name its commonest causes.
737. Describe the procedure for examination of the tactile sense.
738. On what part of the body is tactile discrimination keenest? Least acute?
739. How should one examine the pressure sense?
740. Explain examination of the temperature sense. Pain sense. Muscular sense. Articular or tendinous sense.
741. What is ataxia? How caused?
742. What is the Romberg test?
743. Briefly describe cerebellar ataxia.
744. Define anesthesia; hemianesthesia; hyperesthesia.
745. What sensory effects follow unilateral lesion of the cord?
746. Name some causes of hemianesthesia.
747. What is the probable cause of bilateral anesthesia of the lower extremities?
748. Explain the referred tenderness of visceral disease.
749. What is Head's Law of Pain Distribution?
750. What conditions cause loss of the muscular, articular, and tendinous senses?
751. What conditions are suggested by diminished reflexes?
752. What is the diagnostic significance of exaggerated reflexes?
753. Tell how to test the cutaneous reflexes.
754. Discuss the diagnostic value of the superficial reflexes.
755. Describe the test for the jaw-jerk; elbow-jerk; wrist-jerk.
756. Describe the test of the knee-jerk.
757. How is the ankle-jerk elicited?
758. Describe the manner of testing the light reflex and the accomodation reflex.
759. Discuss the diagnostic significance of the deep reflexes.
760. Name the organic reflexes from whose abnormalities diagnostic conclusions can be drawn.
761. What conditions may cause incontinence of faeces? Retention?

762. What conditions may cause incontinence of urine? Retention?
763. Name the commonest causes of dysphagia.
764. What signs and symptoms suggest that a hemiplegia is due to hemorrhage, embolism, or thrombosis?
765. What are the cardinal symptoms of brain abscess?
766. What are the cardinal symptoms of brain tumor?
767. What is the location of the lesion in motor aphasia?
768. What is signified by loss of taste in the anterior two-thirds of the tongue?
769. Locate the lesion in word deafness.
770. Name the groups or types of diseases of the spinal cord and medulla.
771. What are the characteristics of the anterior horn nuclei group?
772. Describe acute anterior poliomyelitis.
773. Describe progressive muscular atrophy.
774. Give cardinal symptoms of progressive bulbar paralysis.
775. Make a diagnosis of amyotrophic lateral sclerosis.
776. Name the varieties of myelitis.
777. From what diseases must transverse myelitis be differentiated?
778. Give symptoms of transverse myelitis.
779. Describe a case of spina bifida. What is its cause?
780. Give symptoms of hemorrhage into the substance of the cord.
781. State causes and symptoms of caisson disease.
782. What class of symptoms accompany tumor of the cord?
783. What is the Brown-Sequard syndrome?
784. Give pathology and symptoms of syringomelia.
785. What is the pathology of locomotor ataxia?
786. Describe the development of locomotor ataxia through its various stages.
787. What are the cardinal symptoms of tabes dorsalis?
788. What are the symptoms of Friedrich's ataxia?
789. Describe Little's disease.
790. What is pachymeningitis? Leptomeningitis?
791. Give symptoms of acute spinal leptomeningitis.
792. Give symptoms of acute cerebral leptomeningitis.

793. Describe acute tuberculous meningitis.
794. Describe the onset, course and duration of acute cerebrospinal meningitis.
795. Discuss the symptoms of acute cerebrospinal meningitis.
796. What are the predisposing causes of apoplexy? The exciting causes?
797. Describe the attack of apoplexy.
798. Make a diagnosis of apoplexy during the period immediately following the seizure.
799. Describe the post-hemorrhagic developments of apoplexy.
800. How can you determine the fact of pons apoplexy? Cerebellar apoplexy?
801. From what conditions must apoplexy be differentiated? State points of difference.
802. What is the prognosis in intracranial hemorrhage?
803. Give symptoms of acute cerebral softening.
804. State the cardinal symptoms of brain abscess.
805. Describe the clinical picture in hydrocephalus.
806. Describe the clinical picture in infantile cerebral palsy.
807. What are the cardinal symptoms of brain tumor?
808. What is the symptom-complex in multiple sclerosis?
809. Define neuralgia; tarsalgia; Morton's neuralgia; sciatica.
810. Describe the progress of herpes zoster. What is its pathology?
811. Give pathology of tic douloureux. State its symptoms.
812. Describe multiple neuritis.
813. Make a diagnosis of phrenic nerve paralysis.
814. To what is combined brachial paralysis usually due? How may it be recognized?
815. What is Bell's palsy? How caused? How recognized?
816. Describe the clinical picture in pseudo-hypertrophic muscular paralysis.
817. Define neurosis. Name five neuroses.
818. Define epilepsy. Name its two commonest types.
819. Describe the typical grande mal.
820. Describe the course, duration, and prognosis in epilepsy.
821. Describe petit mal.
822. Differentiate between epilepsy and hysteria major.
823. Describe hystero-epilepsy.

824. State Auerbach's theory as to the cause of migraine.
825. Define migraine. Give its symptoms.
826. Define hysteria. What are its causes?
827. Describe a case of hysteria minor.
828. What additional features characterize hysteria major, beyond those of hysteria minor?
829. Under what circumstances may a case be positively diagnosed as hysteria?
830. Define neurasthenia and discuss its causes.
831. What are the cardinal symptoms of neurasthenia?
832. Discuss the traumatic neuroses.
833. Define Sydenham's chorea. Huntington's chorea.
834. Give symptoms of Sydenham's chorea.
835. What is "habit spasm"? "Saltatory spasm"?
836. Name the varieties of torticollis.
837. Define paralysis agitans and give synonyms.
838. Describe the clinical picture in paralysis agitans.
839. What is Parkinson's mask?
840. Name as many occupation neuroses as possible.
841. Make a diagnosis of tetany.
842. What is Raynaud's disease? Erythromelalgia?
843. Briefly describe acromegaly.
844. Define illusion; hallucination; clouding of consciousness.
845. What is disorientation? Delusion?
846. Define obsession; flight of ideas; circumstantiality.
847. Define amnesia; paramnesia; hyperamnesia.
848. Describe a typical febrile delirium.
849. What are the mental symptoms accompanying diabetes mellitus?
850. Give mental symptoms in uraemia.
851. Describe delirium tremens.
852. Make a diagnosis of chronic alcoholism.
853. What are the symptoms of opiumism?
854. Describe a typical cocaine addict.
855. Describe a typical case of paranoia.
856. What is dementia praecox?
857. Make a diagnosis of general paresis.

858. Define feeble-mindedness; imbecility; idiocy.
859. Describe the nerve supply to the brain.
860. Describe the nerve supply to the eye; the ear; the nose.
861. Give the innervation of the pharynx; the larynx; the trachea.
862. By what pathways is the thyroid gland innervated?
863. What nerves and plexuses supply the bronchi? The lungs?
864. Explain the nerve mechanism of the heart.
865. By what nerves is the diaphragm controlled?
866. Name the nerves connected with the stomach.
867. Describe the nerve ramifications to the liver.
868. By what nerves is the gall-bladder supplied?
869. How is the function and condition of the pancreas regulated?
870. State nerve ramifications to the spleen.
871. Give the nerve supply of the small intestine.
872. How are the large intestines innervated?
873. State the formation, location, and distribution of the renal plexus.
874. Give the innervation of the urinary bladder.
875. From what source do the suprarenal capsules receive their nerve supply?
876. How are the ovaries supplied with nerves?
877. Give nerve supply to the uterus.
878. Define philosophy.
879. What is the relation of nervous physiology to the philosophy of nerve action?
880. What is life force?
881. What is the essential difference between vegetable and animal life?
882. What is somatic life?
883. What is the relation of nerve energy to physical and chemical energy?
884. What is the difference between the life which is expressed through the brain as perception and that which is expressed through a gland as secretion?
885. What is the distributing mechanism for life force?
886. What factor determines the function of the individual nerve impulse?
887. Discuss the generation of the nerve impulse.

888. Discuss the manner of transmission of the nerve impulse.
889. Is the nerve impulse electrical in nature? Give reasons for your opinion.
890. Discuss the relation of structural to functional development.
891. What is the relation of nerve energy to organic function in the human body?
892. To what extent does nerve action influence growth, nutrition, and repair?
893. How many kinds of nerve energy are there? Why do you say this?
894. Discuss the selectivity of nerve-cells for stimuli.
895. In what manner, or manners, do neurons communicate with each other?
896. Discuss the differences between reflex, conscious, and intermediate nerve action.
897. What is the subconscious mind?
898. Discuss the influence of the emotions upon bodily function.
899. What is the effect of obstruction of the flow of nerve energy?
900. In what way may spinal nerve root obstruction affect the functions of the sympathetic?

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